Industrial Mineral Background Paper No. 5

Ontario and the Mineral Filler Industry

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Cover: Steep Rock Resources Inc.
Calcite mine, Darling Township, Ontario.

Table of Contents

page

Preface

1. Executive Summary 1
- Objective
- Study Area
- Method of Study
- Definition
- Scope of Study
- Economic Base
- Geology of Ontario
- Barite
- Carbonate Minerals
- Kaolin
- Mica
- Silica
- Talc
- Marketing
- Markets
- Transportation

2. Introduction 5
- Mineral Fillers
- Filler Markets
- The Study Area
- The Potential for New Mineral Filler Production
- Acknowledgements

3. Geology of Ontario 11
- The Precambrian Shield 11
  - The Superior Province
  - The Southern Province
  - The Grenville Province
- The Phanerozoic Lowlands 13
  - The Hudson Bay Lowlands
  - The Great Lakes Lowlands
  - The St. Lawrence Lowlands
- The Pleistocene Mantle 14

4. Barite 15
- Summary 15
- Introduction 15
- Geology 15
  - Vein Deposits
  - Bedded Deposits
  - Residual Deposits
- Major Canadian Deposits 16
  - Newfoundland
    - Buchans
    - Collier Point
  - Nova Scotia
    - Brookfield
    - Walton
    - Lake Ainslie
  - Ontario
    - Hemlo
    - Matachewan
    - Tionaga
    - Timmins

page

        - McKellar Island
        - Spar and Jarvis Islands
        - Southeastern Ontario
        - Madoc
    - British Columbia
        - Parson and Brisco
        - Invermere
        - Spillimacheen
        - Northeastern British Columbia
- United States Producers 21
    - Nevada
    - Missouri
- Mining Methods 22
- Processing Technology 25
    - Primary Processing
    - Fine Grinding
- Uses, Specifications and Prices 25
    - Oil and Gas Well Drilling Muds
    - Barium Chemicals
    - Glass
    - Other Non-Filler Uses
    - Filler Applications
        - Paint
        - Plastics
        - Rubber
        - Carpet backing
        - Putty, Caulks and Sealants
    - Prices of Filler Grade Barite
- Production and Consumption 27
- Competitive Materials 28
- Trends 28

5. Carbonates 29

- Summary 29
- Geology and Ontario Occurrences 29
    - Grenville Marble
        - Belmont Township
        - Burleigh Township
        - Guilford Township
        - Hagerman Township
        - Hungerford Township
        - Huntingdon Township
        - Marmora Township
        - Ross Township
        - Spence Township
    - Marl
        - Harvey Township
        - Hungerford Township
    - Vein Deposits
        - Palmerston Township
- Mining Methods 34
- Processing Technology 34
        - Crushing, Grinding and Classifying
        - Additives and Grinding Aids
- Uses, Specifications, Prices 37
    - Specifications
        - Particle Size

page

Whiteness
Mineralogical and Chemical Purity
Grade Designations
Uses
Paint
Plastics
Paper
Paper Filling
Paper Coating
Putty, Caulks, Sealants
Rubber
Vinyl Flooring–Vinyl Fabrics
Carpet Backing
Jointing Compounds
Asphaltic Products
Dolomite Fillers 46
Producers 47
Canadian Producers
United States Producers
Consumption 49
Paper
Paint
Plastics and Rubber
Others
Competitive Materials 50
Paint
Carpet Backing
Vinyl Flooring–Sheeting
Putty, Caulks and Sealants
Plastics
Paper
Rubber
Joint Cements
General
Trends 51

6. Kaolin 53

Summary 53
Geology 53
Producers and Occurrences 54
Canadian Occurrences
Prairie Provinces
Quebec
Nova Scotia
Ontario
Moose River Kaolin
Copper Mine Point
United States Producers
Georgia–South Carolina
Alabama
California
Florida
Texas
United Kingdom
Brazil

page

Mining Methods 62
  Exploration Techniques
  Open Pit Mining
  Hydraulic Mining
Processing Technology 64
  Preliminary Laboratory Studies
  General Process Considerations
  Primary Processing
  Primary Wet Processing
  Secondary Wet Processing
    Removal of Abrasive Components
    Fractionation of Kaolin
    Bleaching of Kaolin
    Magnetic Separation
    Delamination
    Organic Contaminants
    Dewatering and Filtration
    Drying
  Dry Processing
  Calcined Kaolin
  Surface Treated Kaolin
Uses, Specifications, Prices 72
  Paper
    Paper Coating Grades
    Paper Filling
      Delaminated Kaolin
      Calcined Kaolin
  Paint
    Water Washed Kaolin
    Delaminated Kaolin
    Calcined Kaolin
  Plastics
    Water Washed and Air Floated Kaolin
    Delaminated Kaolin
    Calcined Kaolin
    Surface Coated Kaolin
  Rubber
    Air Floated Kaolin
    Water Washed Kaolin
    Calcined Kaolin
    Surface Coated Kaolin
  Adhesives
    Air Floated Kaolin
    Water Washed Kaolin
    Delaminated and Calcined Kaolin
    Surface Treated Kaolin
  Carpet Backing
    Air Floated Kaolin
    Water Washed Kaolin
  Putty, Caulks and Sealants
    Air Floated Kaolin
    Water Washed Kaolin
    Calcined Kaolin
  Other Minor Filler Applications
    Printing Ink
    Fertilizers
    Pesticides
Production and Consumption 77

page

- Canadian Consumption
- Production
- Competitive Materials 78
- Trends 79

7. Mica 81

- Summary 81
- Geology 81
  - Muscovite
  - Phlogopite and Biotite
  - Ontario Deposits
    - Kaladar Muscovite Schist
    - Clarendon Muscovite Schist
- Producers 82
  - Quebec
  - United States
    - North Carolina
      - Spruce Pine Area
      - Kings Mountain Area
    - Other Producing States
  - United Kingdom
- Mining Methods 84
- Processing Technology 85
  - Primary Processing
  - Dry Grinding
  - Wet Grinding
  - Micronizing
  - Mica Separation Processes
    - Flotation
    - Differential Screening
    - Air Separation Techniques
    - Magnetic Separation
  - Delamination of Mica
  - Evaluating Mica Deposits
- Uses, Specifications, Prices 88
  - Paint
  - Plastics
  - Rubber
  - Roofing Products
  - Gypsum Board Joint Cements
  - Oil Well Drilling Muds
  - Mica Paper
  - Welding Rod Coatings
  - Fire Extinguishers
- Production 93
- Competitive Materials 93
- Trends 94

8. Silica 99

- Summary 99
- Geology 99
  - Types of Silica Deposits
    - Sand
    - Sandstone
    - Quartzite

page

Pegmatites and Veins
Tripoli
Diatomite
Rottenstone
Novaculite
Other Sources
Ontario Occurrences 100
Surficial Sands
Campement d'Ours
Westree Sand
Kaolin-Quartz Sands
Sylvania Sandstone
Oriskany Sandstone
Potsdam Sandstone
Pegmatites and Veins
Bar River Quartzite
Lorrain Quartzite
Producers 110
Canadian Producers
Nova Scotia Sand and Gravel Limited
Indusmin Limited, St. Canut, Quebec
Indusmin Limited, Midland, Ontario
Steel Brothers Canada Limited
SIL Silica Limited
United States Producers
Ottawa Silica Company, Illinois
Ottawa Silica Company, Michigan
PGS Corporation, West Virginia
PGS Corporation, Pennsylvania
Bank Sands, Michigan and Ohio
Mining Technology 113
Processing Technology 115
Natural Sands
Sandstone
Quartzite
Quartz
Wet or Dry Processing
Beneficiation Processes
Filler Production
Environmental Protection
Uses, Specifications, Prices 118
Paint
Plastics
Putty, Caulks and Sealants
Rubber
Adhesives
Wood Fillers
Asphaltics
Buffing Compounds
Foundry Mould Washes
Household Cleansers
Ceramics
Glass
Bricks
Concrete Block
White Cement
Production and Consumption 121

page

- Canada
- United States
- Competitive Materials 123
- Trends 123

9. Talc 125

- Summary 125
- Geology 125
- Ontario Producers 125
  - Canada Talc Industries Limited
  - Steetley Talc Limited
- Other Ontario Occurrences
  - Ram Petroleums Limited
  - Madoc Talc and Mining Company Limited
  - Eldorado Mining and Milling Company
  - Canadian Magnesite Mines Limited
- Quebec Producers
  - Bakertalc Incorporated
  - Talc BSQ Incorporated
- Talc Producers in the United States
  - New York
  - Vermont
  - Texas
  - Montana
  - California
- Mining Methods 131
- Processing Technology 131
  - High Purity Talc
  - Mixed Talc Deposits
  - Surface Treatment
- Uses, Specifications, Prices 134
  - Particle Size
  - Brightness
  - Mineralogical Purity
  - Abrasiveness
  - Paint
  - Plastics
  - Paper
    - Paper Filling
    - Paper Coating
  - Putty, Caulks and Sealants
  - Jointing Compounds
  - Rubber
  - Adhesives
  - Asphaltics
  - Cosmetics
  - Health Care Products
  - Ceramics
- Production 139
- Competitive Materials 141
- Trends 141

10. Marketing 143

- Introduction 143
  - Direct Sales

page

Indirect Sales
Cost Effectiveness
Paper 144
Introduction
Paper Industry–Structure, Size and Location
Filler Consumption in Paper
Trends
Paint 148
Introduction
Paint Industry–Structure, Size and Location
Filler Consumption in Paint
Trends
Plastics and Rubber 153
Introduction
Filler Use
The Industry
Canada
United States
Filler Consumption
Barite
Calcium carbonate
Kaolin
Mica
Silica
Talc
Dolomite
Carpet Backing
Vinyl Tile
Putty, Caulks and Sealants 160
Introduction
Filler Use
Calcium carbonate
Talc
Mica
Kaolin
Silica
Barite
Filler Consumption
Adhesives 162
Introduction
Filler Use
Calcium carbonate
Air floated kaolin
Water washed kaolin
Talc
Silica
Filler Consumption

11. Transportation 165

Introduction
Aspects of Transportation Related to Mineral Characteristics
Mode of Transportation
Transportation Costs

page
Selected References 169

Minerals
  Barite
  Carbonates
  Kaolin
  Mica
  Silica
  Talc
  Minerals–General
Markets
  Paper
  Paint
  Plastics and Rubber
  Markets–General

Tables

page
1. The more important mineral fillers. 6
2. United States states and populations in the primary study area. 8
3. Major barite producers, 1982. 16
4. United States barite mines and mills, 1981. 22
5. Major non filler applications for barite. 26
6. Primary uses for barite fillers. 27
7. Estimated barite filler market, 1980-1985. 28
8. Grade designations and typical properties of calcium carbonate fillers. 39
9. Primary uses for carbonate fillers. 40
10. Summary of applications for calcium carbonate filler in plastics. 42
11. Estimated carbonate filler market, 1980-1985. 50
12. Chemical composition of Moose River kaolin. 55
13. Kaolin producers of United States. 61
14. Major kaolin filler applications. 71
15. Minor kaolin filler applications. 72
16. Major non filler applications for kaolin. 72
17. Canadian imports of kaolin. 78
18. Canadian consumption of kaolin by use. 78
19. Canadian consumption of kaolin for paper. 78
20. Kaolin production in United States. 79
21. United States kaolin production by type. 79
22. United States production of selected kaolin fillers. 79
23. Estimated kaolin filler market, 1980-1985. 80
24. Mica producers in the United States, 1983. 83
25. Primary uses for flake mica. 90
26. Secondary non-filler applications for mica. 90
27. Estimated mica filler market, 1980-1985. 94
28. Major silica occurrences in Ontario. 100
29. Mineralogy of some surficial sands in Ontario. 102
30. Chemical compositions of two Ontario sand deposits. 102
31. Composition of quartz sands, Moose River Basin. 103
32. Sieve analyses of quartz sands, Moose River Basin. 104
33. Typical composition of Sylvania sandstone. 106

page
34. Typical composition of Oriskany sandstone. 106
35. Typical composition of Potsdam sandstone. 109
36. Pegmatite deposits opened in Ontario. 109
37. Typical compositions of Precambrian quartzites. 110
38. Some silica producers of Canada and the United States. 111
39. Major filler applications for silica. 118
40. Minor filler applications for silica. 119
41. Major non-filler applications for fine silica. 119
42. Canadian consumption of silica by use. 121
43. Canadian production and trade in silica. 122
44. Ontario silica production, consumption, trade, 1977. 122
45. Silica production in the United States. 123
46. United States silica consumption by use, 1980. 124
47. Estimated silica filler market, 1980-1985. 123
48. Talc occurrences in Eastern Ontario. 126
49. Filler applications for talc. 135
50. Annual talc production. 140
51. Canadian consumption of talc. 140
52. Estimated annual talc filler market, 1980-1985. 140

53. Value of paper mill shipments, 1978. 145
54. Value of paper and paperboard shipments. 147
55. State ranking for paper within the study area. 147
56. Features and benefits of the major paper fillers. 148
57. Estimated annual filler consumption for paper, 1980-1985. 148
58. Composition of a typical interior wall paint. 149
59. The Canadian paint industry, 1978. 150
60. Features and benefits of the major paint fillers. 152
61. Value of paint shipments. 152
62. Estimated annual filler consumption for paint, 1980-1985. 153
63. Major markets for elastomers. 154
64. Major markets for plastics. 154
65. Value of shipments for plastics, rubber, wire and cable products. 155
66. United States manufacturing plants, plastic and rubber products. 157
67. Filler utilization in plastics and elastomers. 157
68. Estimated annual filler consumption in plastics and rubber, 1980-1985. 159
69. Estimated filler consumption in carpet backing, 1980-1985. 160
70. Annual filler consumption in putty, caulks and sealants, 1980-1985. 162
71. Rail freight rate comparison, 1981, and highway distance chart. 166

Figures

1. The Study Area. 7
2. Geology of Ontario. 12
3. Principal Producers of Barite. 17
4. The McKellar Island Barite Vein. 20

page
5. Flowsheet: Barite Concentrator, Mountain Springs, Nevada. 23
6. Flowsheet: Barite Grinding Plant, Battle Mountain, Nevada. 24
7. Grenville Marbles of Eastern Ontario. 31
8. Conceptual Flowsheet: Calcium Carbonate Production. 36
9. Principal Producers of Filler-grade Calcitic and Dolomitic Carbonate. 48
10. Geology of the Moose River Basin. 56
11. East-West Section through Moose River Basin. 57
12. Kaolin Mines and Plants of Georgia. 60
13. Distribution of Kaolinization in Southwest England. 63
14. Flowsheet: Composite Optional Kaolin Processing Plant. 66
15. Kaolin Particle Sizes for Paper. 69
16. Conceptual Flowsheet–Dry Beneficiation of Mica. 87
17. Conceptual Flowsheet–Wet Grinding of Mica. 89
18. Campement d'Ours Silica Sand Deposit. 101
19. The Sylvania Sandstone in Southwestern Ontario. 105
20. Oriskany Sandstone in South-Central Ontario. 107
21. Distribution of Potsdam Sandstone in Eastern Ontario. 108
22. Geology Map of northeast Badgeley Island. 112
23. Principal Producers of Silica. 114
24. Conceptual Flowsheet–Silica Sand and Filler Plant. 117
25. Vertical Section, Henderson Talc Zone. 127
26. Principal Producers of Talc. 130
27. Conceptual Flowsheet–Talc Filler Products. 133
28. Distribution of Pulp and Paper Mills. 146
29. Distribution of Paint Manufacturers. 151
30. Plastics, Rubber, Wire & Cable Plants. 156

Photographs

1. The Matachewan barite vein before mining in 1968. 18
2. The Tionaga barite vein as it appeared in 1962. 19
3. McKellar Island; coarse platy barite and blocky calcite. 21
4. The Spar Island barite vein, Lake Superior. 21
5. White Valley marl deposit, Harby Tp., Peterborough Co. 33
6. Dry and Lime Lakes, Hungerford Tp., Hastings Co. 33
7. Drilling on typical muskeg terrain in the Moose River Basin, 1978. 55
8. Slurry of kaolin and quartz sand recovered by the reverse circulation drilling technique. 58
9. Indusmin Badgeley Island crushing plant. 111

Colour Plates

1. Extender Minerals barite mine, Matachewan, Ontario. 95
2. White marl shoreline, Dry Lake, Marlbank, Ontario.
3. Calcite vein, Palmerston Township, Ontario.
4. Steep Rock calcite quarry, Tatlock, Ontario. 96
5. Steep Rock calcium carbonate plant, Perth, Ontario.

page
6. White kaolinitic quartz sand, Adam Creek, Moose River Basin, Ontario. 97
7. Refractory kaolin clay, Adam Creek, Moose River Basin, Ontario.
8. Koizumi muscovite schist deposit, Kaladar, Ontario.
9. W.R. Barnes sandstone quarry, Storrington Township, Ontario.
10. Indusmin quartzite quarry, Badgeley Island, Ontario.
11. Canadian Silica quartzite quarry, Sheguiandah, Manitoulin Island, Ontario. 98
12. Canada Talc plant at Madoc, Ontario.
13. Talc concentrate cake at drum filler–Steetley Talc Concentrator, Penhorwood, Ontario.

Preface

Ontario's wealth of industrial minerals has attracted industrialists as well as private citizens throughout the years.

This present study is the first comprehensive discussion of seven industrial mineral fillers in Ontario—their geological occurrence and significance in North America, mining and processing technology, product specifications and uses, market potential and transportation aspects. The seven mineral fillers (barite, calcite, dolomite, kaolin, mica, silica and talc) were selected because of strong current interest by mineral producers, users and the general public.

Many books and reports, some dating from before Confederation, have been produced by the provincial and federal governments to describe Ontario's industrial minerals. The late Dr. Donald F. Hewitt, of the Ontario Ministry of Natural Resources, through his authorship of numerous industrial mineral books and reports, was responsible for raising our general understanding of the valuable role these minerals play in everyday life.

Dr. Hewitt was well known for the excellence of his work and for his strong interest in industrial minerals. A rare accolade from him to a colleague was: ''What little you do, you do well''. This book deserves the same compliment because it meets the high standards Dr. Hewitt set for himself and demanded of others and we expect it too, will contribute to an enhanced recognition of the importance and value of Ontario's industrial minerals.

1 Executive Summary

Objective

The objective of this study is to assess the market potential for certain specific Ontario minerals for use in industrial filler applications. The minerals studied are barite, kaolin, mica, silica, talc and the carbonate minerals (calcium carbonate and dolomite). The filler markets reviewed include paper, paint, plastics, rubber, vinyl tile, carpet backing, putty, caulks, sealants and adhesives.

Study Area

The market area of primary importance centres on southern Ontario, and includes southern Quebec and fifteen nearby states of the United States. The rationale for choosing these limits is mainly the return range of 24 hour truck haulage, a range that generally seems to have some economic relevance in 1983.

Method of Study

The study is based in part on a draft report prepared by Industrial Minerals, Inc. as a result of research undertaken in 1980-81 under contract to the Ontario Ministry of Natural Resources. Marketing data and other statistics presented in that report were up-dated by reference to detailed government reports, trade journals and professional papers. In only a few cases were personal contacts made with actual suppliers, consumers and distributors of filler minerals.

Geological data, and information on mining and processing techniques, were generally familiar to the two authors, augmented by reference to numerous texts and other sources duly referenced.

Definition

Mineral fillers are finely ground mineral matter used in a wide range of industrial applications as low cost additives to increase the bulk of many commercial products, and usually also to improve their physical properties. Because they extend (and usually enhance) the properties of the products in which they are used, they are also known as mineral extenders.

Scope of Study

While there are dozens of minerals used as industrial fillers, only a few are extensively used. The minerals reviewed here–barite, carbonate minerals, kaolin, mica, silica and talc–are among the most common, and all of them occur in Ontario.

These minerals, and the markets they serve, are detailed in respect to geological occurrence, major deposits and producers, mining and processing methods, product specifications, markets and prices, competitive materials and trends, and transportation modes.

Economic Base

Ontario's population, at 8.5 million (1980), is 35 percent of Canada's total. The fifteen nearby U.S. states included in the study area have a combined population of 92.9 million (1980), 41 percent of the total United States.

Ontario and Quebec account for 60 percent (ie. Can.$214 billion) of total Canadian industrial activity based on Gross National Product for 1983. The fifteen U.S. states in the study area account for half (ie. U.S.$387 billion) of total industrial activity in the United States, based on statistics for Value Added by Manufacture for 1980.

Thus the marketing area for suitable Ontario minerals embraces a total population of 100 million people and an industrial base valued at more than half the total for both countries.

Geology of Ontario

Ontario's area of a million square kilometres is dominated by the Canadian Shield, an upland area of Precambrian crystalline rocks. Both to the north and to the south these ancient rocks slope beneath Phanerozoic lowlands comprised of flat, relatively undisturbed sedimentary rocks, largely Cambrian to Devonian in age. The scouring affects of several major glaciations during the last million years, and the redeposition of unconsolidated soil and rock debris from the melting ice, has been dominant in shaping the land surface.

Precambrian rocks, particularly the Grenville Province of southeastern Ontairo, are the major Ontario source of the minerals studied, except for kaolin which occurs predominantly in Cretaceous sediments on the James Bay Lowland. Silica, barite and the carbonate minerals may also be found in Paleozoic rocks on the Phanerozoic lowlands, particularly those marginal to Lake Ontario.

Barite

Barite, barium sulphate, is an unusually heavy non-metallic mineral that is used principally as a weighting agent in drilling muds to control formation pressures in deep oil drilling projects. Weight is also its main asset in its rather limited use as a filler in certain paints and plastics.

Narrow barite veins of high purity and whiteness have been the only commercial source in Ontario. A vein near Matachewan has been operated on a small scale for more than a decade by Extender Minerals of Canada Ltd., producing only for filler markets. Newly discovered bedded barite deposits associated with gold mineralization at Hemlo may prove of interest for drilling mud markets.

Extensive bedded deposits in Nevada are the principal source of drilling mud barite in the United States. Residual deposits in Missouri are more important for filler grades.

White barite's relatively high cost and scarcity is limiting its greater use for fillers; calcium carbonate is its most common substitute even though it lacks the high density.

An estimated 30,000 tonnes of barite are consumed annually in paints in the study area; and 8,000 tonnes for plastics and rubber.

Carbonate Minerals

Calcium carbonate is the most extensively used filler mineral, finding application in a large variety of industrial products. Limestones that have been metamorphosed to marbles of high purity and whiteness are the principal source of higher-grade fillers. Although white dolomite is also commonly used in Europe, it is not readily accepted as an alternative to calcium carbonate in North America.

A quarry in high purity white marble in the Perth area of eastern Ontario, operated by Steep Rock Resources Inc., is the principal source of high-grade calcium carbonate fillers in eastern Canada.

Because of its relatively low cost and widespread availability, calcium carbonate faces little competition in filler markets. Estimated annual consumption in the study area is 930,000 tonnes, largely in plastics, rubber, paint, paper and drywall compounds.

Kaolin

Kaolin is almost an ideal filler, and like calcium carbonate finds application in a great variety of industrial products. Paper is its principal market, where it is used for both filling and coating.

Extensive sedimentary kaolin deposits in Georgia are the world's major source of paper-grade kaolin. Residual deposits in Cornwall, England, are of next importance. High quality filler kaolin is not produced in Canada, but sedimentary deposits on the James Bay Lowland in northeastern Ontario may be suitable; further testing is necessary.

Few fillers can match the benefits of kaolin. However, calcium carbonate is whiter and less expensive, and can be used instead of kaolin for paper made by the alkaline sizing process. A trend towards this conversion has been identified in the paper industry.

Estimated annual market for kaolin in the study area is 2,555,000 tonnes, of which 2,200,000 is accounted for by paper; plastics, rubber, paints and adhesives are the other major markets. Since Canada is primarily a producer of newsprint and wood pulp, which contain no filler, Canada is not a large consumer of kaolin. However, all its requirements are imported at an annual cost of U.S. $23 million (1981), not including imports from the United Kingdom.

Mica

The most unique property of mica is its platy habit, and the ease with which it can be split into thin flakes of high aspect ratio. The toughness of these flakes gives mica great reinforcing properties in filler roles. Mica-reinforced plastics are expected to experience major growth, particularly in the automobile industry. Traditional markets in paint, joint cements and oil drilling fluids have also been augmented by its use in a number of asbestos markets.

Deposits of phlogopite schist in Quebec are being worked exclusively for mica flakes, although most commercial sources are byproducts of feldspar and lithium mining in North Carolina. A large deposit of muscovite schist at Kaladar in southeastern Ontario is being tested.

Mica has yet to realize its expected growth in plastics, but that growth should favour the study area because of its concentration of automobile manufacturing. Meanwhile its estimated market in the study area is 40,000 tonnes, due mainly to its use in drywall compounds and paint.

Silica

Silica is an abrasive mineral and its use in fillers is small. Its traditional filler application has been in paint, but its use in plastics is expanding. Large volumes of silica are used in non-filler applications such as glass, foundry sand and flux.

Ontario's sole commercial source is Precambrian quartzite, quarried on Badgeley Island in northern Georgian Bay and shipped in lump form for ferrosilicon production or for further grinding to glass sand at a plant in Midland. However, other potential sources are available, and it seems likely that new domestic silica production will be stimulated by escalating haulage costs of imported silica which now accounts for 70 percent (by value) of Ontario's needs.

Finely ground silica shares the filler market with artificially precipitated silica, which, although non-abrasive is considerably more expensive. Estimated annual filler market for natural silica in the study area is 49,000 tonnes.

Talc

Talc is distinguished particularly because of its softness; hence its use in cosmetics and health care products. Its most important filler applications are in paint and as a pitch absorbant in the making of paper pulp. It also has an important role controlling thermal expansion in ceramic bodies, as well as reducing the firing temperatures necessary and hence conserving fuel.

Commercial talcs have varied considerably in composition and properties, due to admixture with tremolite, dolomite and other minerals, but the trend now is to increased purity of the talc product.

Ontario produces talc from a quarry near Timmins and an underground mine at Madoc. Timmins talc has been particularly successful for pitch control in the paper pulp industry of eastern North America. At Madoc substantial new reserves were discovered in 1982, providing incentive for expanded processing facilities.

Estimated annual market for talc fillers in the study area is 225,000 tonnes.

Marketing

Opportunities are believed to exist in Ontario for further industrial mineral development, particularly for silica, kaolin, mica and barite, not solely for their filler markets, which for silica and barite are relatively small, but for other larger volume industrial markets as well. Kaolin and mica are not presently produced in Ontario, and domestic production of silica and barite is inadequate for the total market. Escalating transportation costs for imported minerals are creating a price structure favourable to increased domestic production even at the expense of extensive beneficiation.

The marketing of filler minerals can be handled by the producer through direct sales or indirect sales. Direct sales employ company salesmen acting exclusively for the producer. Indirect sales involve independent distributors, sales agents, brokers and jobbers. There is a trend towards increased use of direct sales.

Markets

While there are a great many specific uses for filler minerals, most of them can be categorized into a few major industries. These include paper, paint, plastics and rubber (including carpet backing and vinyl tile), putty, caulks and sealants (including drywall compounds), and adhesives.

Large volumes of kaolin, and some calcium carbonate, are used to fill and coat paper, while talc is increasingly being used for pitch control in paper pulp. An estimated 2,200,000 tonnes of kaolin, 80,000 tonnes of calcium carbonate, and 55,000 tonnes of talc are consumed annually in paper production in the study area. However, since Ontario is primarily a producer of pulp and newsprint it is not presently a large market for kaolin or calcium carbonate. A total of 663 pulp, paper and paperboard mills are located in Canada and United States; about 63 percent of them are in the study area.

Fillers are an important part of most paint formulations, extending and enhancing the properties of the paint. All the minerals reviewed in this report can be used in paint, but calcium carbonate, kaolin and talc are the main ones. An estimated 362,000 tonnes of filler minerals are used annually in paints, of which calcium carbonate represents one-third and kaolin and talc each one-quarter, within the study area. About 57 percent of the larger paint plants in Canada and United States are located in the study area.

The plastics and rubber industries include also carpet backing and vinyl tile, significant consumers of mineral fillers. While all the minerals reviewed in this report are used to some extent, calcium carbonate and kaolin are the main ones; an estimated 425,000 tonnes of calcium carbonate and 200,000 tonnes of kaolin are consumed annually in the study area. Of a total of more than 7,000 major producing plants in Canada and United States, 60 percent are located in the study area.

Putty, caulks and sealants, including drywall compounds, are large users of calcium carbonate as well as some talc and mica. An estimated 250,000 tonnes of calcium carbonate are used in drywall compounds alone within the study area; plus 30,000 tonnes in other caulks and sealants, and 20,000 tonnes in putty. About 60 percent of production from these industries is generated in the study area.

Adhesives, including all types of glue and other bonding agents, use fillers to reduce shrinkage, improve temperature resistance, and reduce cost. Kaolin is the principal filler used, amounting to an estimated 40,000 tonnes annually within the study area. About 300 of the 572 adhesive and sealant producers in United States are located within the study area.

Transportation

Transportation cost is a major factor in determining competitiveness in the filler industry. In many instances haulage costs are greater than the base value of the filler at the mine or plant. Escalating transport costs from remote sources are stimulating interest for new or increased Ontario production of some filler minerals.

Shipment of dry finely ground mineral fillers in bulk or in bags by truck or rail has been the traditional mode. But slurry shipments in tanker cars and tank trucks are increasing, particularly where both the producer and consumer have wet processing facilities.

Whereas rail was favoured for long hauls, rail costs have escalated; and greater capital investment is involved in handling facilities at both ends. Increasingly, trucks are being used over distances that can be serviced within a 24-hour round trip time frame. Trucks allow greater flexibility, faster service, less inventory and less capital investment in handling and storage facilities at the consuming plant.

2 Introduction

This report is an economic review of six mineral fillers which may have potential for development in Ontario. It deals specifically with barite, talc, silica, mica, kaolin and the carbonate minerals: calcite and dolomite.

Mineral Fillers

Mineral fillers are finely ground mineral matter used in a wide range of industrial applications as low cost additives contributing certain attractive physical properties to the finished products. Kaolin fills between the wood fibres in paper to give it body and a smooth hard finish. Mica adds strength and rigidity to plastics. Barite adds weight and acts as a carrier for the pigment in paint.

Because mineral fillers extend and enhance the properties of the products in which they are used, they are also known as mineral extenders. The terms "filler" and "extender" are considered synonymous in this report.

A great many minerals are used as fillers. The more common ones are listed in Table 1 along with some of their principal uses and the properties that make them useful.

This report reviews some of the more important industrial mineral resources in Ontario which have, or might have, potential for mineral fillers. Of the six commodities under review, only mica and kaolin are presently not produced commercially in Ontario. However, increased productive capacity may also be warranted for silica, talc, and barite.

Filler Markets

The major markets for mineral fillers are paint, paper, plastics, rubber, adhesives and floor coverings; but there are many others: putty, pesticides, wire and cable coatings, caulking and asphaltic compounds, oil cloth, wallpaper, joint cements, inks and sealants are some others.

Although the early function of a filler was primarily as a bulking material to reduce the overall cost of the product, the enhanced properties which it can provide may be more important than the saving in cost. A mineral filler may be used to modify any one or more of the following aspects (Severinghaus 1975, p. 235):

Cost
Physical characteristics
Flow characteristics
Fire resistance
Density
Heat conductivity
Colour or brightness and opacity
Hardness, brittleness, impact strength
Deformity, viscosity, softening point
Processing problems
Electrical conductivity

The beneficial effects which a filler may impart are, of course, related to its own physical characteristics. Particle shape, hardness, colour, density, refractive index and chemical inertness are some of the important ones. But because these properties attain an optimum level of value that is often related to fineness and particle size distribution in any specific application, numerous grades of a particular filler are necessary to adequately serve the market. Finer particle sizes tend to fill smaller voids giving smoother surfaces.

Particle shape is often a major consideration in selecting a filler. For example the platy shapes of kaolin and mica contribute to strength, toughness and flatness.

Hardness is often of major concern because of the abrasive effect on processing equipment. Talc, kaolin and carbonate minerals are less abrasive, but silica gives greater abrasion resistance in rubber and paint.

Ideally a filler should be white. High whiteness is essential in paper and paint, but slightly off-white fillers can be tolerated in plastics, rubber, adhesives and caulking compounds.

The unusual heaviness of barite makes it desirable in certain paints and gives it special value in products where resistance to radiation is important.

Index of refraction is a major consideration for a filler used in paint because it has a considerable effect on the hiding power of the paint film.

Chemical inertness allows the use of kaolin as a filler and coater in paper regardless of the acidity or alkalinity of the sizing process. While calcium carbonate can replace kaolin in basic sizing environments it is highly reactive and unsuitable in an acidic environment, the most common commercial process.

Numerous other physical characteristics of specific mineral fillers are of special importance for certain uses. Indeed, new applications continue to be found, some based on very subtle variations in properties. Also of growing importance is the practice of coating or surface treatment of mineral particles with certain coupling agents or metal stearates, which may result in substantially modified characteristics and open up a new range of applications.

The filler industry is not restricted to materials of mineral origin. Synthetic fillers, some of which are of exceptionally high purity may be artificially derived from mineral material or may be organic in origin.

The Study Area

Industrial markets in southern Ontario, southwestern Quebec, and the northeastern part of the United States are the obvious targets for Ontario minerals. These markets are typically within a 24 hour turn-around trucking range, a range which we have taken to be of primary interest for mineral fillers.

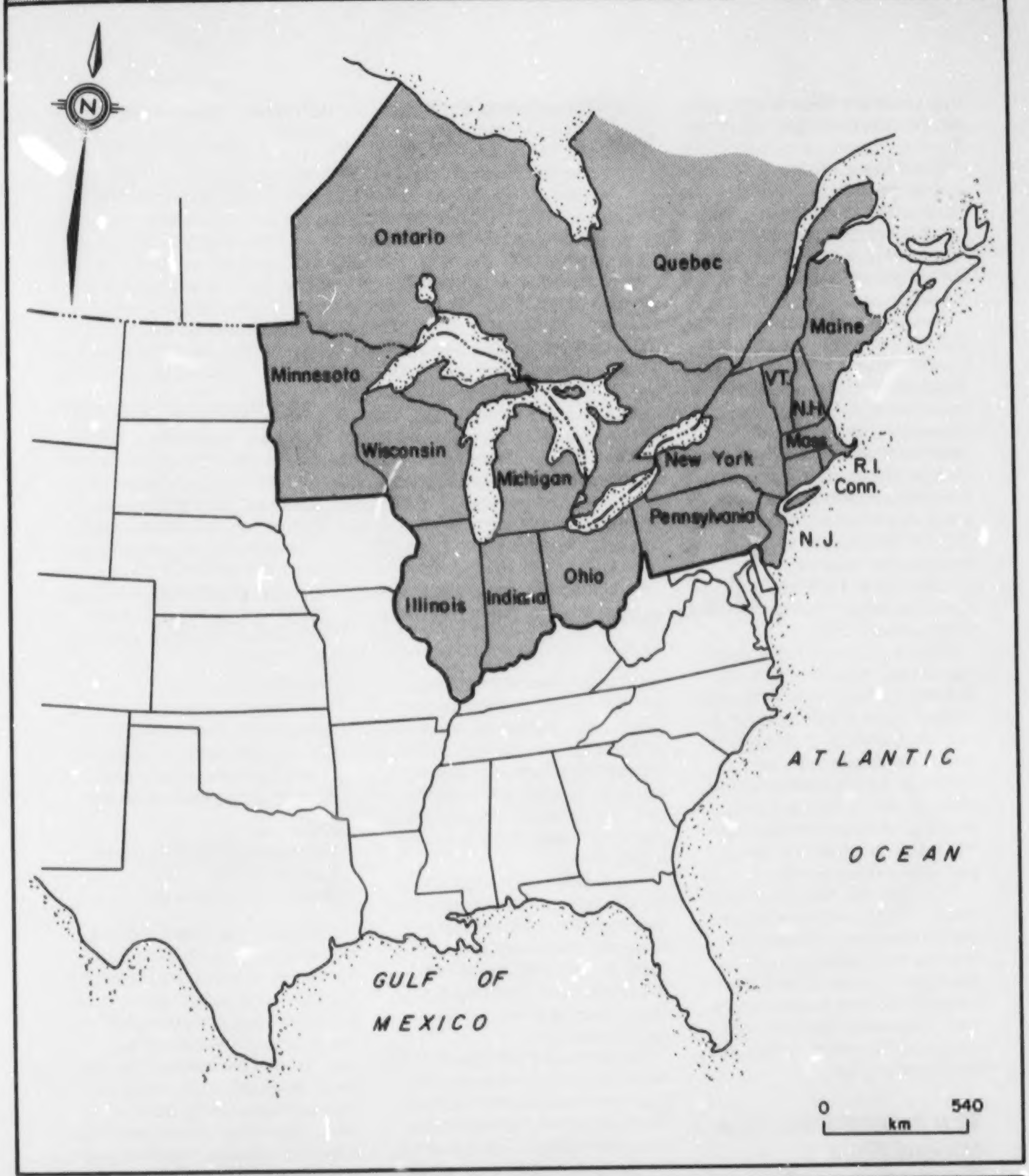
The primary study area thus includes fifteen U.S. states in closest proximity to Ontario and Quebec (Fig. 1). These states, their 1980 populations, and a measure of their industrial activ-

Table 1 The More Important Mineral Fillers

	Major Filler Uses	**Distinguishing Properties**
Asbestos	Floor tile, plastics.	The most fibrous mineral filler. Uses based on reinforcing and viscosity control effects.
Barite	Rubber, paint, and urethanes.	The highest density mineral filler; also inert.
Calcium carbonate	Paint, plastics, paper, putty, vinyl flooring, and many others.	White, soft, non-abrasive, inexpensive.
Diatomite	Paints, paper, plastics, pesticides, cementitious mixtures and most filler uses.	An inert or reactive opaline silica depending on use; unique microscopic structure.
Dolomite	Asphalt roofing, carpet backing, caulking compounds.	Low oil absorption, non-abrasive, inexpensive.
Fuller's earth	Pesticides principally, but some in greases and paper.	Important as pesticide dust diluent; absorptive capacity relatively good; price low.
Gypsum	Paints, paper, cotton goods, pesticides.	Low cost. A minor filler material used raw or calcined.
Kaolin	Paper, paint, adhesives, oil cloth, plastics, rubber, ink, pesticides.	Good white colour, low cost, low absorption, a versatile filler.
Limestone	Asphalt, fertilizers, insecticides, paints, rubber, plastics, and many others.	Abundant and cheap, particles soft, soluble in acids; has largest tonnage use of all fillers.
Mica	Plastics, paint, roofing, joint cement, rubber and wallpaper.	Thin platy structure unique, valuable for electrical properties, plastic reinforcing.
Perlite	Fines used in paint, loose fill, drilling muds, plastics, and misc.	Lightweight vesicular structure. Filler uses not large.
Pumicite	Stuccos, plasters and paint.	Natural vesicular structure, harsh. Filler uses minor.
Pyrophyllite	Insecticides, asphalt roofing, paint, rubber, battery boxes.	Like talc, but more refractory.
Rock dusts	Asphaltic compounds and cheap filler uses.	Low cost; chemical stability, strength.
Silica	Paints, bitumens, foundry facings, etc.	Hardness, inertness, strength, and low cost.
Talc	Paints, insecticides, roofing, rubber, asphalt, paper, cosmetics, textiles.	Soft platy structure, good adhesion.
Vermiculite	Fertilizers, pesticides.	Filler grades are fines from expanded aggregate; filler uses not large.

Reference: Severinghaus 1975, p.236, with modification.

FIGURE 1



THE STUDY AREA

ity (in terms of Value Added by Manufacture) are given in Table 2.

Table 2: U.S. States in the Primary Study Area

State	Population (1980)	Industrial Activity (V.A.M.* 1980) Millions of U.S. dollars
Maine	1,124,660	3,600
New Hampshire	920,610	3,606
Vermont	511,456	1,687
Massachusetts	5,737,037	23,221
Rhode Island	947,154	3,545
Connecticut	3,107,576	15,973
New Jersey	7,364,158	30,137
Pennsylvania	11,866,728	47,046
New York	15,557,288	58,140
Ohio	10,797,419	50,176
Indiana	5,490,179	26,921
Illinois	11,418,461	50,543
Michigan	9,258,344	36,723
Wisconsin	4,705,335	21,323
Minnesota	4,077,148	14,305
Total	92,883,553	386,946
Total United States	226,504,825	773,441

Reference: Anonymous, Statistical Abstracts of U.S., 1982.

*V.A.M. = Value added by manufacture.

The fifteen U.S. states represent 41 percent of the total population of the United States, which in 1980 was 226,504,825. More importantly, this area accounts for half of total U.S. industrial activity.

Ontario's population of 8,480,127 (1980) is 35 percent of Canada's total of 24,088,700. Together Ontario and Quebec represent nearly two-thirds of Canada's population, most of which resides in southern Ontario and southwestern Quebec. More importantly, the two provinces account for 60 percent ($214 billion) of total Canadian industrial activity, which was estimated at Can. $360 billion (gross national product) in 1983 (Anonymous 1983).

Thus the primary study area represents not only a large portion of total North American population, but more than half of its industrial activity. Canada and the United States are each others major trading partners, and many of their industries and corporate structures are interlocking, just as are their social patterns and family ties.

Having so defined the primary study area, it is important to recognize also that important peripheral markets exist such as the river counties of Iowa and certain industrial areas of Maryland, Delaware, Missouri, and along the Ohio River in Kentucky and West Virginia.

The Potential For New Mineral Filler Production

Opportunities are believed to exist in Ontario for further industrial mineral production, including the minerals discussed in this study for mineral filler applications. Many of Ontario's needs for industrial minerals and fillers are imported from the United States, currently at high cost due to unfavourable exchange rates and high transportation costs. Ontario is geographically well located relative to the extensive markets in the industrialized areas bordering the Great Lakes, and a significant portion of both country's industry and population is located in this area.

The current exchange rate of the Canadian dollar favours the export of domestic industrial minerals, including fillers. Thus, many known deposits which may have been uneconomic ten years ago deserve reconsideration.

The evaluation of known or newly discovered mineral deposits will require detailed studies of technical, marketing and financial aspects. Each mineral project will have its own special characteristics relative to the following factors:

TECHNICAL
- Size and location of the deposit.
- Quality and quantity of the mineral reserves.
- Degree of beneficiation required to produce commercially acceptable products.
- Environmental factors.

COMMERCIAL
- Total market potential.
- Geographic market area.
- Distribution costs i.e. sales and transportation costs.
- Cost of competitive products.

FINANCIAL
- Capital and operating costs.
- Cost of capital.
- Return on investment.

Geographical location of the deposit and its production facility relative to the market is an important factor. Many filler products have a relatively low value, and distribution costs may exceed the value of the material. Because consumers evaluate products on the basis of performance and delivered cost, it is critical to determine the geographic area in which the products can be marketed competitively.

In addition to the marketing aspects, it is also important to examine the technical implications of the project. The size and quality of the deposit, the mining method and the processing required to bring the products to acceptable quality are factors that must be carefully evaluated.

Each will have an impact on the economic viability of the project.

There are few, if any, short cuts. It is of paramount importance to determine that there is a market; furthermore, that the deposit is of the quality and size that can support the operation over a long period. Likewise the products produced must be acceptable in the marketplace and capable of being sold competitively and profitably.

Acknowledgements

In 1982 a draft report by Industrial Minerals, Inc. was prepared on mineral fillers for the Ontario Ministry of Natural Resources. It dealt particularly with the minerals covered in the present study, and it defined the markets and transportation aspects for mineral fillers in eastern North America. Indeed, it formed the basis for this volume, and was freely and extensively consulted. The authors of this volume wish to record their indebtedness to Messrs. S.J. Lefond and R.E. Blair of Industrial Minerals, Inc.

In 1982 C.H. Kline & Co. Inc. published Part 1 of their most recent review of the filler industries, dealing particularly with fillers used in the paper and carpet backing industries. In 1983 they released Part 2, which deals with filler use in paints, adhesives, putty, caulks and sealants. The final Part, expected in 1984, will deal with plastics and rubber. In keeping with their request for confidentiality, the Kline study was used primarily to confirm our own findings and was not directly quoted. Direct quotations of earlier Kline studies are acknowledged in each case in the text. The authors acknowledge their indebtedness to the Kline studies, and recommend them to readers seeking greater detail than contained herein.

The gathering of data for a study of this magnitude involves the review of a great many professional papers, trade journals and government documents. These are appropriately acknowledged in the text and fully referenced in the bibliography.

This study was undertaken at the suggestion of S.E. Yundt of the Mineral Resources Branch, Ontario Ministry of Natural Resources, and was conducted under the guidance of D.G. Minnes. The assistance of these individuals was most appreciated.

3 Geology of Ontario

Ontario, the most populous and one of the largest of Canada's twelve provinces and territories, has traditionally been the hub of commerce for the nation. Although an inland province it is bounded on the north by Hudson and James Bays, and on the south by four of the Great Lakes (Fig. 2). It either contacts or has direct access through the Great Lakes to eight U.S. states: New York, Pennsylvania, Ohio, Michigan, Indiana, Illinois, Wisconsin, and Minnesota. And it has access to ocean shipping by way of the St. Lawrence Seaway. To the east it is flanked by the Province of Quebec; on the west by the Province of Manitoba.

Extending nearly 1600 km in both a north-south and an east-west direction, Ontario's area of one million square kilometres is dominated by the Canadian Shield, an upland area of Precambrian crystalline rocks that underlies 62 percent of the land. While the geological record has been long and complex, erosion has been the most obvious influence in reducing the Shield to a peneplane of only moderate relief. Maximum elevations do not exceed 670 m above sea level.

Both to the north and to the south the Precambrian surface slopes beneath Phanerozoic lowlands comprised of flat undisturbed sedimentary rocks. In the south, these are the principal agricultural lands in the province; but to the north the relief is so minimal that the lowland is largely a muskeg plain fringed against Hudson and James Bays by extensive mud flats.

Over all has been imposed the effects of several major glaciations during the last million years. The land is still rebounding from being depressed by enormous thicknesses of continental ice, and the profusion of fresh-water lakes and rivers are the remnants of basins and channels formed by glacial meltwaters.

The Precambrian Shield

Canada's Precambrian Shield is like a yoke enveloping Hudson Bay. It is the basement rock for much of the Northwest Territories, northern Saskatchewan, Manitoba, Ontario and Quebec. Its outcrop extends in a wide belt across the central part of Ontario from northwest to southeast.

The Shield has long been a stable platform on which younger sediments have been successively deposited and largely eroded. Large scale earth movements and major metamorphism were events of the distant past. However, such early events have been dated and the Shield is now divisible into a few major areas, each of which contain rocks which have suffered similar and contemporaneous structural and metamorphic disturbance. Thus the Precambrian shield in Ontario can be divided into three areas, or structural provinces, from oldest to youngest: the Superior Province, the Southern Province, and the Grenville Province.

The Superior Province

The Superior Province is the largest and oldest of the structural provinces in Ontario. Rocks of this area are imprinted by a major period of metamorphism which ended about 2,500 million years ago. Superior rocks comprise most of the northern part of the Shield in Ontario.

Formation of the Superior Province began as the product of volcanic activity in Early Precambrian time. Successive extrusions of mafic and felsic lavas were mixed with elastic sediments in an oceanic environment. Chains of volcanic islands and island arcs were built up from the ocean floor, and sediments eroded from earlier volcanic and granitic rocks were deposited on their flanks. Both volcanic and sedimentary rocks were intruded by stocks, dikes and sills of varying composition, and the whole was subjected to intense deformation accompanied by widespread intrusion of granitic magma. This last event, known as the Kenoran Orogeny, ended about 2,500 million years ago, and the area has been stable and inactive since except for erosion which has gradually reduced it to its present nearly level peneplaned surface.

Today the Superior Province is represented by extensive batholiths of granite interspersed with belts of greenstone and feldspathic gneisses. Gold, copper, zinc, and iron are being mined from Superior rocks. Among the industrial minerals, serpentine and talc are being mined, and deposits of lithium, phosphate, vermiculite, granite and magnesite show promise for the future.

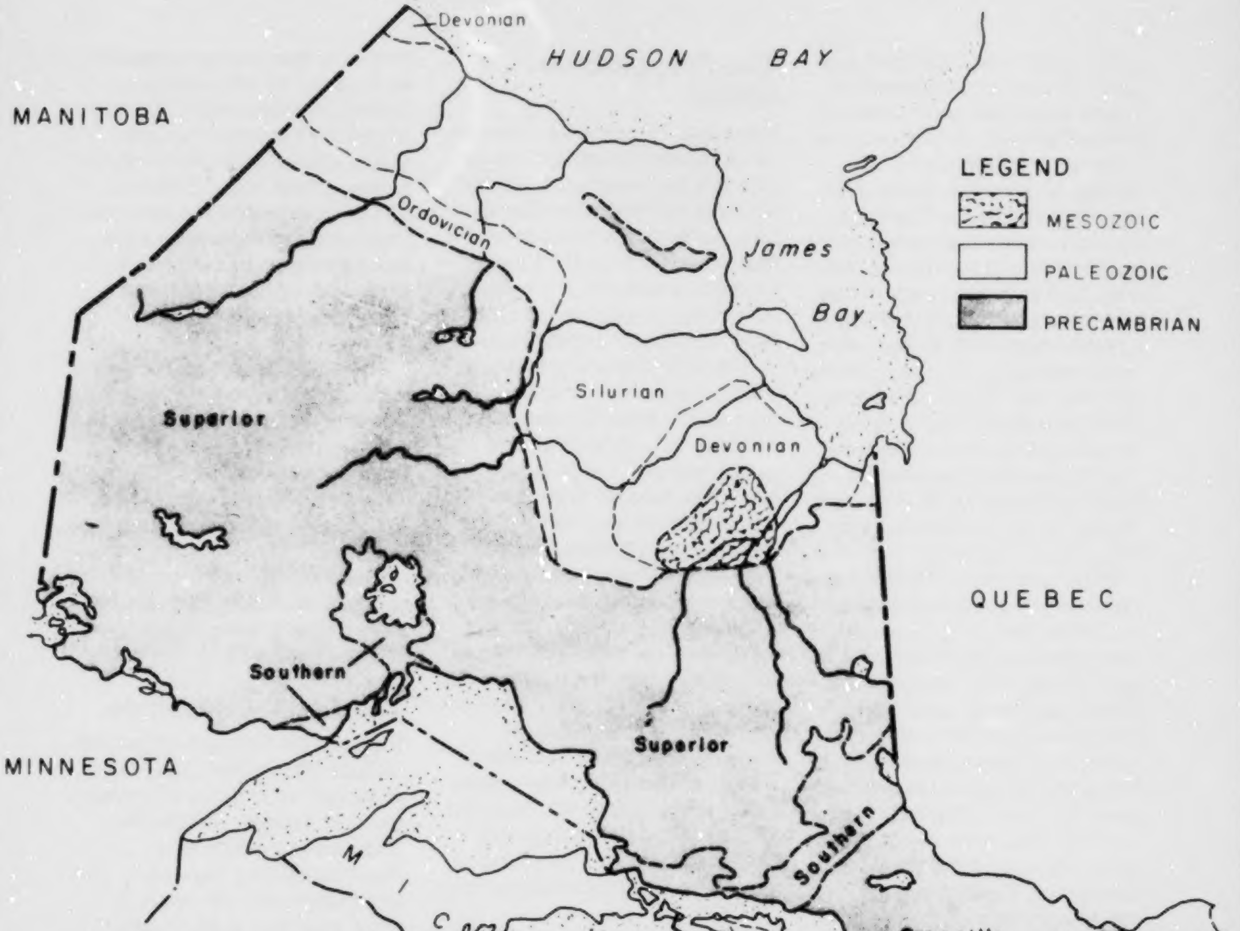
The Southern Province

Rocks of the Southern Province include Middle and Late Precambrian sediments, and intrusions of diabase and granite. They are much less extensive than rocks of the Superior group, and mainly occur in two locations: near the head of Lake Superior, and east from Lake Superior through Sudbury and into Quebec. These two areas may be linked by a belt passing beneath Lake Superior and continuing westward into Minnesota.

Flat-topped hills of diabase in Ontario's Lakehead area are remnants of sills that marked the last stage of igneous activity in the western part of the Southern Province. These sills, along with numerous dikes, were intruded into relatively undisturbed clastic sedimentary rocks that were deposited on the peneplaned Superior surface in Middle and Late Precambrian time. Silver and barite mineralization accompanied the diabase in the form of narrow veins.

In the eastern area, clastic sedimentary rocks known as the Huronian sequence were deposited north of Lake Huron and

Figure 2



GEOLOGY OF ONTARIO

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eastwards. These were subjected to several periods of folding, faulting and metamorphism, and were intruded by dikes and sills of diabase and some granitic rocks. The Southern Province in this area has provided great mineral wealth to Ontario. The rich nickel, copper, and precious metal ores of Sudbury belong to the Southern Province, as do the uranium deposits of Elliot Lake and the silver veins of Cobalt. Among the industrial minerals, barite and high purity quartzite are important.

The Grenville Province

In southern Ontario, the Shield is represented entirely by Grenville rocks. Their north boundary, known as the Grenville Front, is marked by a zone of highly metamorphosed gneisses formed by compression and thrust faulting against the more rigid rocks of the Southern Province. The Grenville Front closely approximates the line which is normally taken in dividing northern and southern Ontario.

The Grenville consists of clastic sedimentary rocks of Middle Precambrian age, and in its southern part by extensive limestone and volcanic rocks of Late Precambrian age, all intruded by extensive and widespread batholiths of granite and local occurrences of gabbro, anorthosite, nepheline and alkalic syenites, and scattered feldspathic pegmatites. Nearly all of the Grenville was subjected to high-grade regional metamorphism between 1,200 and 1,050 million years ago, resulting in widespread gneissic imprint and alteration of limestone to marble. However, a small area in the southern Grenville escaped the severe metamorphism and is the host area for minor gold mineralization and some talc and mica schists.

The Grenville is particularly noted for its variety of interesting mineralization, and is a favourite collecting area. The nepheline rocks, pegmatites, and marbles are especially important for industrial minerals. Mineral production from Grenville rocks has included uranium, iron, gold, magnesium, nepheline syenite, feldspar, apatite, corundum, beryl, mica, fluorite, barite, talc, calcium carbonate, quartz, graphite, and marble.

The Phanerozoic Lowlands

Paleozoic sedimentary rocks lap the Precambrian Shield both in the far north of Ontario and in the south. These rocks are related to three basins of deposition marginal to Ontario: the Hudson Bay basin in the north, and the Michigan and Appalachian basins in the south.

An arch of Grenville rocks which extends into New York State east of Lake Ontario divided the southern Paleozoic lowlands into two segments: the St. Lawrence Lowland to the east, and the Great Lakes Lowlands to the west. In northern Ontario a broad Paleozoic Lowland is marginal to both Hudson and James Bays.

The Hudson Bay Lowland

Limestones, dolomites, and shales of Ordovician, Silurian and Devonian age are about 2,000 metres thick in the deepest part of the Hudson Bay basin, but on the Ontario shore reach a maximum of about 800 metres. They underlie a broad, flat, poorly drained muskeg plain, and outcrops are practically confined to the banks of a few major rivers. Access to much of this area is restricted to canoe or float-equipped aircraft. Borings for oil and gas have not been rewarding, but impressive beds of massive white gypsum are exposed in Devonian outcrops south of James Bay.

A smaller basin superimposed on James Bay basin, known as the Moose River basin, contains the only significant occurrence of Mesozoic sediments in Ontario. These consist of an interbedded sequence of unconsolidated quartz sands, kaolinite clays and lignite up to 150 metres thick. The basin lies south of James Bay and is crossed by a rail line to Moosonee, one of the few points of access on the James Bay shore. The area has great potential for the development of kaolin, fireclay, and silica sand in addition to its lignite fuel resources.

The Great Lakes Lowlands

A flat undisturbed sequence of Paleozoic sedimentary rocks underlies all of southern Ontario marginal to Lakes Ontario and Erie and the southern shores of Lake Huron and Georgian Bay. In the extreme southwest corner of the province these sediments are about 1,500 metres thick. They include limestone, dolomite, shale and sandstone from Cambrian to Devonian in age. Actually this sedimentary sequence dips very gently towards the southwest, so that the various rock units are successively exposed in outcrop from oldest to youngest as one proceeds in a southwesterly direction across southern Ontario.

Important amounts of oil and gas are produced from Cambrian, Silurian and Devonian sediments in southwestern Ontario. Gypsum and massive beds of salt are mined from the Silurian. Chemical grade lime is produced from the Devonian, and dolomitic lime from the Silurian. Ordovician shales are extensively used for brick manufacture. Ordovician and Silurian limestones, dolomites and sandstones are used for building stones and crushed aggregate.

The St. Lawrence Lowland

Only a small portion of the St. Lawrence Lowland occurs in Ontario; the rest being to the east in Quebec and the Maritime Provinces. In Ontario, Paleozoic rocks occupy the extreme southeast portion of the province east of the Frontenac arch of Grenville rock. Sandstones of Cambrian age, and limestones and shales of Ordovician age are represented. These rocks dip gently to the southeast, but they have been moderately disturbed by block-faulting.

Ordovician shale is used for brick-making, and limestone for crushed aggregate. Cambrian sandstone of the Potsdam Formation shows promise as a source of silica. Deposits of limestone and sandstone have been used in the construction of many fine buildings throughout the area.

The Pleistocene Mantle

Erosion has been the dominant factor in shaping the land since Devonian time in Ontario. Widely scattered remnants of Paleozoic rock on the Precambrian Shield suggest that the Paleozoic was more widespread than at present and over wide areas of the Shield may have formed a continuous cover.

Erosion has been particularly active during the last million years when four major ice sheets spread southwards across Ontario followed successively by interglacial periods. In fact it is generally believed that Ontario is presently enjoying an interglacial stage. In any event, these continental glaciers effectively removed all loose weathered material and scoured the bedrocks over which they passed, and the accumulated debris was finally deposited at the melting ice fronts in southern Ontario and the adjoining states of the United States.

The last ice sheet, the Wisconsinan, began to recede about 14,000 years ago, and by 10,000 years ago most of southern Ontario was finally free of the melting ice. As the icefront retreated northward a series of large ancestral lakes occupied the basins of the Great Lakes. Swollen rivers of meltwater deposited sand and gravel along their banks and varved clays in the lakes and ponds which they fed.

More than any other stage in the geological history of Ontario, the Pleistocene has shaped the land as we know it today. Such surficial features as moraines, eskers, kames, drumlin fields, raised beaches and lake plains are all due to Pleistocene glaciation. Deposits of sand, gravel, clay, marl and peat are part of the Pleistocene and Recent geological record.

4 Barite

Summary

Barite is the mineral name for barium sulphate. Its natural occurrence is in compact masses or bladed crystals, often white in colour. Commercial sources are found in veins, bedded replacements and residual deposits.

Its unusual heaviness is its most unique property, and it is extensively used as a weighting agent in drilling muds to control pressures in deep oil well drilling projects. Weight is also its principal asset in its use as a filler in paints and plastics. It is also used in making certain barium chemicals, and finds minor application in glass.

In the past decade Ontario production has been limited to small annual tonnages for filler uses from a vein of white barite near Matachewan. A major supplier to the Texas and Louisiana oil fields was the large replacement deposit at Walton, Nova Scotia, closed in 1978. Bedded barite deposits associated with gold mineralization discovered in 1982 at Hemlo, Ontario, may prove to be a significant new source of barite.

In the United States, extensive bedded deposits in Nevada are the major source of drilling grades of barite, while residual deposits in Missouri are the most important filler sources.

Barite has few competitors in the mineral field. However, its relatively high cost is limiting its greater use as a filler.

Introduction

Barite, $BaSO_4$, owes its industrial value to its heaviness; with a specific gravity of 4.4 it is unusually heavy for a non-metallic mineral. Its principal use is as a weighting agent in oilwell drilling muds, and this use probably accounts for more than 90 percent of world production. Use of barite in glass-making, fillers and the manufacture of barium chemicals accounts for the rest.

Barite occurs in veins, bedded and residual deposits. Small vein deposits have been the only source of barite in Ontario, but recently discovered bedded deposits associated with gold mineralization in the Hemlo area are of considerable interest. Both residual and bedded deposits are of major importance in the United States. Canada's major producer, now closed, was the large bedded replacement deposit at Walton, Nova Scotia. Throughout the world, barite is a common host mineral for copper, zinc, lead and silver in veins and replacement deposits, and it is often recovered as a by-product of mining operations for these metals.

In veins, barite may be nearly white and of high purity, but pink and grey varieties are also common. It often occurs in coarse platy crystals forming cockscomb structures and botryoidal masses. Lumps in these shapes are common in residual deposits where the barite has been weathered out of limestone or shale. A fine-grained compact dark coloured variety is more typical of bedded deposits.

Barite can be mined by both open pit and underground techniques. Steeply dipping bedded and vein deposits are sometimes mined initially by open cut, and subsequently by underground methods. Beneficiation can range from simple hand sorting to gravity separation and flotation. Improved whiteness can sometimes be achieved by bleaching in hot dilute sulphuric acid.

In Canada, small amounts of barite are produced in Newfoundland, Nova Scotia, Ontario and British Columbia. In 1980 its total value was $4.4 million. In the same year imports from the United States were valued at $4.2 million (Vagt 1983, p. 2).

Principal barite production in the United States is from Nevada and Missouri. However, Georgia, Missouri and Tennessee are the main sources of barite for fillers and chemicals. In 1981, barite production in the United States was a record 2.58 million tonnes valued at $102 million (U.S.). The United States also imported 1.75 million tonnes from China and Mexico.

An estimated 30,000 tonnes of barite are consumed annually as paint filler in the study area; 8,000 tonnes for plastics and rubber.

The use of artificially precipitated "blanc fixe", a fine grained barium sulphate of high purity, and "lithopone", a mixture of barium sulphate and zinc sulphide, as fillers and pigments in paints has all but ceased.

Geology

Commercial barite deposits are of three types: Vein, bedded and residual.

Vein Deposits

Vein deposits are those which have been emplaced in breccia zones, joints or faults, crystallizing from solutions rich in barium sulphate, possibly hydrothermal in origin. In Ontario they are known in both Precambrian and Paleozoic terrains. They are typically narrow irregular steeply-dipping tabular bodies, sometimes of high purity but often including varying proportions of calcite, quartz, fluorite and sulphide minerals. Texture of the barite can range from coarsely crystalline to rather fine grained, massive to banded. Barite veins in northern Ontario are often nearly white, but in southeastern Ontario they are more commonly narrow and pink.

Bedded Deposits

Bedded deposits are those which occur in extensive stratiform sequences, usually the result of replacement of limestone. The major commercial deposits of the world are bedded replacement deposits. Canada's major producer at Walton, Nova Scotia, was of this type, as are the extensive deposits of Nevada. The newly discovered barite deposits associated with gold mineralization at Hemlo, north of Lake Superior, are bedded deposits although the mode of deposition has not yet been determined.

Bedded barite is commonly dark coloured, grey to black, due to organic or other impurities. Grades may vary to 95 percent barite, with fine grained quartz, clay minerals and pyrite the most common impurities.

Residual Deposits

Residual deposits consist of barite nodules and fragments in a layer of soil or clay resulting from the weathering of pre-existing rocks which contained the barite. Often the source is a group of narrow barite veins in limestone or dolomite, as in the important deposits of Missouri. Residual deposits may only comprise perhaps 10 percent barite in a clay bed up to 10 m in thickness, but the barite lumps are easily concentrated by washing over a coarse screen. Because of the scouring action of recent glaciation, residual barite deposits are not likely to be found in Ontario.

Major Canadian Deposits

In 1981, barite was produced in Newfoundland, Nova Scotia, Ontario and British Columbia. Ontario production was largely for filler uses; Nova Scotia's was for pharmaceutical purposes; and the other provinces mainly served the drilling industry. Some of the production from British Columbia, and all of the Newfoundland production, was from re-worked mine tailings. Canada's foremost producer ceased production in Walton, Nova Scotia, in 1978.

Newfoundland

Buchans

Production commenced in 1981 by Abitibi-Price Inc. on the extraction of barite from tailings at the Buchans Mine in central Newfoundland. Barite is the main gangue mineral in the lead-zinc-copper sulphide orebodies,

Table 3 Major Barite Producers, 1982

Canada

NEWFOUNDLAND
1. Abitibi-Price Inc., Buchans.

NOVA SCOTIA
2. Nystone Chemicals Ltd., Upper Brookfield.

ONTARIO
3. Extender Minerals of Canada Ltd., Matachewan

BRITISH COLUMBIA
4. Mountain Minerals Co. Ltd., Parson and Brisco.
5. Baroid of Canada Ltd., Spillimacheen.

United States

ARKANSAS
6. Milchem Inc., Glenwood
7. NL Industries Inc., Baroid Div., Montgomery County and Magnet Cove.

CALIFORNIA
8. Industrial Minerals Co., Northern Calif.
9. Rocky Mountain Refractories Co., Nevada County.

GEORGIA
10. Cyprus Industrial Minerals, Cartersville.
11. New Riverside Ochre Co., Cartersville.
12. Southern Talc, Chatsworth.
13. Thompson, Weinman & Co., Cartersville.

IDAHO
14. NL Industries Inc., Baroid Div., Blaine County.
15. Rocky Mountain Refractories Co., Blaine County.

ILLINOIS
16. Seaforth Mineral & Ore Co. Inc., Hardin County.

KENTUCKY
17. Chromalloy American Corp., Marion County.

MISSOURI
18. Agers Brothers Inc.
19. DeSoto Mining Co., Richwood and Kingston.
20. Dresser Minerals, Potosi.
21. General Barite Co., Washington County.
22. Hornsey Brothers, Cadet.
23. Imco Services, Washington County.
24. Missouri Mining Co., Michwood.
25. NL Industries Inc., Potosi.
26. Pfizer

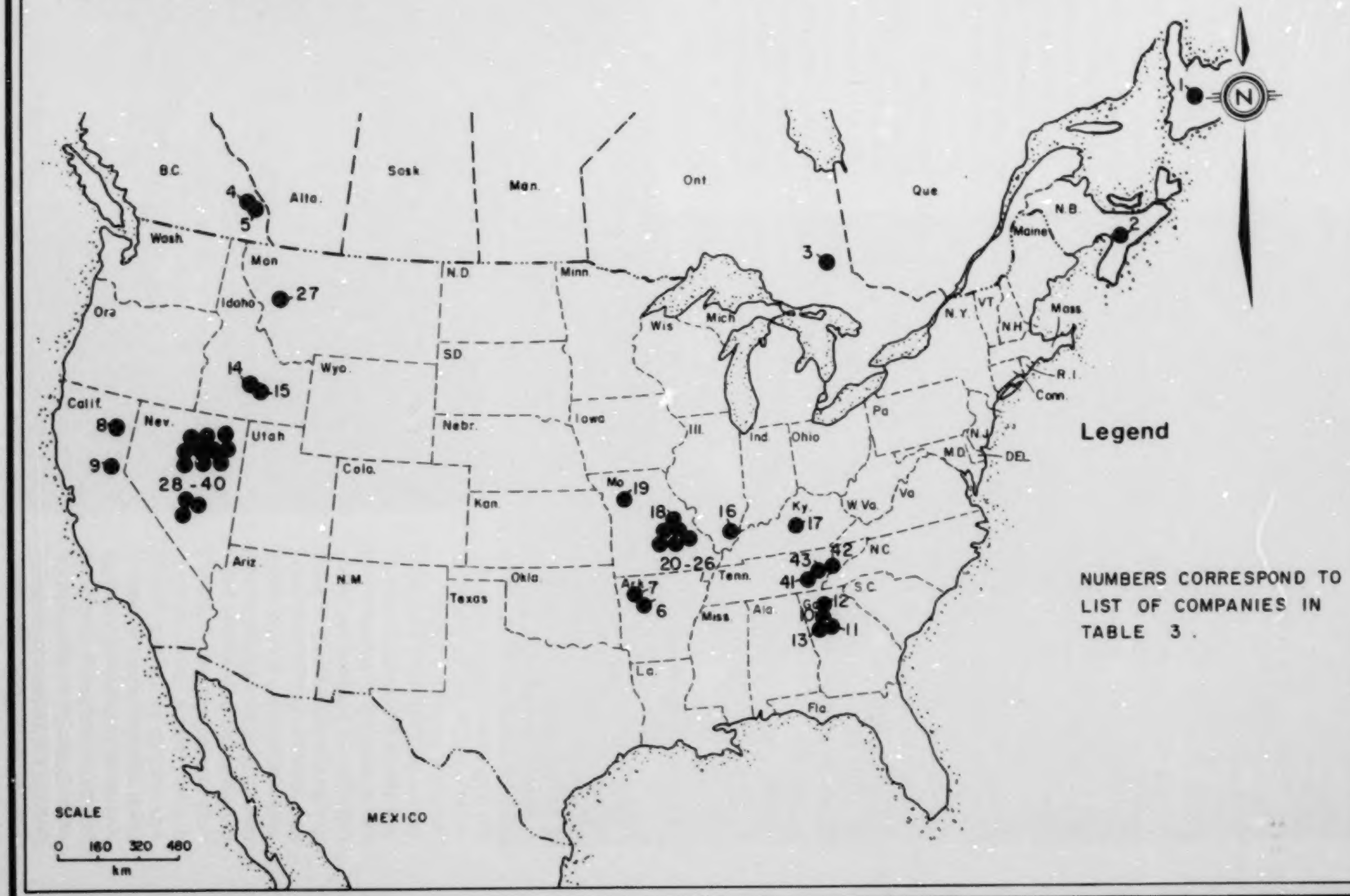
MONTANA
27. Montana Barite Co., Missoula.

NEVADA
28. All Minerals Corp., Nye County.
29. A.W. Arnold & Assoc. Inc.
30. Chromalloy American Corp., Wells.
31. Custom Milling & Supply.
32. Magcobar (Dresser Industries), Battle Mountain.
33. Eisenmann Chemical Co.
34. FMC Corp., Industrial Chemical Group, Lander County.
35. Imco Services, Mountain Springs, Norris and Lander County.
36. Milchem Inc., Bald Mountain, Barse and Rim Rock.
37. NL Industries Inc., Battle Mountain.
38. T. Norris Inc.
39. Old Soldier Mining Co.
40. Standard Industrial Minerals Inc., Nye County.

TENNESSEE
41. NL Industries Inc., Sweetwater.
42. A.J. Smith Co., Laudon County.
43. B.C. & C.R. Wood, Sweetwater.

Figure 3

PRINCIPAL PRODUCERS OF BARITE



Legend

NUMBERS CORRESPOND TO LIST OF COMPANIES IN TABLE 3.

and it comprises up to 46 percent of the tailings which have been accumulating since the mine opened in 1928. An estimated 450,000 tonnes of barite suitable for dilling mud are available.

Collier Point

About 9,000 tonnes of barite were produced in 1980 from an open cut on a narrow (1.5m) vein at Collier Point on the Avalon Peninsula. The vein material averages more than 95 percent $BaSO_4$, but overall reserves are small. Similar veins are common in this part of Newfoundland, and small production from them is expected from time to time in response to increasing offshore drilling activities.

Nova Scotia

Brookfield

In 1980, a small production of pharmaceutical-grade barite was commenced from a vein deposit near Brookfield by Nystone Chemicals Ltd. (Vagt 1983).

Walton

A massive bedded replacement deposit near Walton was worked from 1941 to 1978. This deposit was by far Canada's principal producer, and ranked as one of the largest and purest deposits in the world. It was estimated to contain more than 4 million tonnes grading better than 90 percent $BaSO_4$ (Jewett 1957, p. 54). Apparently a replacement of limestone in a faulted sedimentary sequence of Mississippian and Triassic age, the barite occured with sugary texture in colours ranging through pink, white and grey. The deposit was initially worked by quarrying to depths of about 100 m, and subsequently by an underground block caving method. A lead-zinc-silver sulphide deposit was found associated with the barite at depth, and both were mined through the same shaft. Barite was shipped by boat in crude lump form to grinding plants in Louisiana and Texas. Water and mud seaping into the underground workings eventually forced closure of the mine.

Lake Ainslie

Barite is associated with fluorite in veins to 6 m wide in the Lake Ainslie district of Cape Breton Island. Reserves are reported at about 3 million tonnes grading 44 percent barite and 17 percent fluorite.

Ontario

Until recently, vein deposits of limited extent were the only barite occurrences of significance in Ontario. These were widespread, though not particularly common, in southeastern Ontario, the Timmins-Matachewan area of northeastern Ontario, and in the Thunder Bay area of northwestern Ontario. They have been previously described (Guillet 1963) and only the more important ones are briefly mentioned in the following notes.

Hemlo

The discovery of gold mineralization in the Hemlo area north of Lake Superior in 1982 also disclosed the first significant occurrence of bedded barite in Ontario. Barite may constitute as much as 30 percent of the mineralized metasedimentary bed, occurring with gold, pyrite, and pyroclastic debris believed to have been deposited in small sheltered basins in Precambrian volcanic terrains (Wahl 1983, p.19). The feasibility of commercial production of barite is being considered in association with gold production in the area.

Matachewan

Barite for filler applications has been produced since the early 1970's by Extender Minerals of Canada Limited from a vein deposit near Matachewan. Photo 1 shows the vein as it appeared in 1968 prior to mining by open cut methods. At that time it was exposed on the west shore of Mistinikon Lake, 10 km southwest of

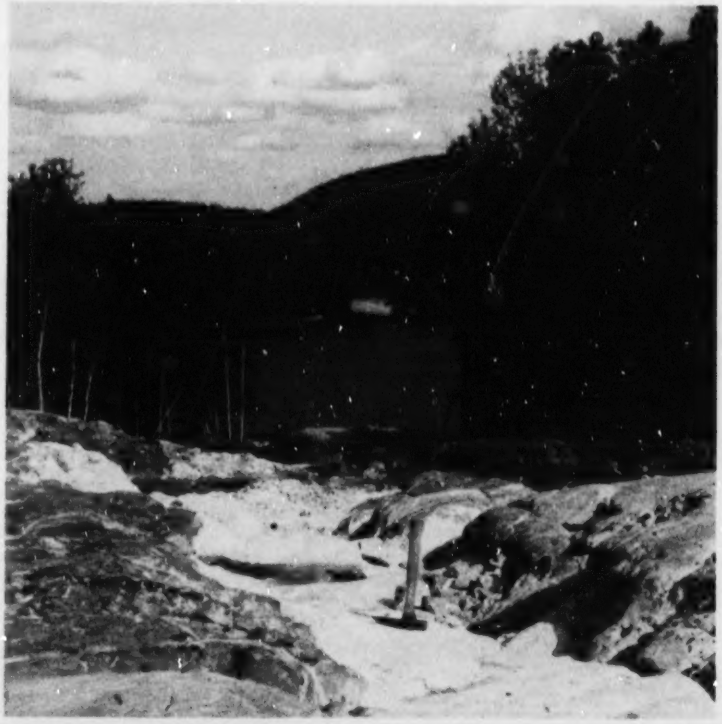


Photo 1 The Matachewan barite vein before mining in 1968.

Matachewan, over a length of 230 m, varying in width to 5 m but averaging about 1.5 m. Vein material is coarsely crystalline white barite with only trace amounts of calcite and quartz. While annual production is small, the product continues to enjoy a good market in paint and plastics.

Tionaga

Small production was recorded at intervals during the period 1920-1940 from a vein of white barite west of Tionaga Station on the CNR 80 km west of Timmins. Photo 2 shows the open cut as it appeared in 1962. The vein was worked over a length of 30 m to a depth of about 12 m; it averages slightly less than 2 m in width.

Timmins

Intermittent production was also recorded between the years 1910 and 1948 from a vein of white barite on the west shore of the Nighthawk River, 30 km southeast of Timmins. The vein is vertical and averages about 1 m in width. It was worked from an adit and several shallow shafts (Guillet 1963, p. 18-19).

McKellar Island

Barite is a common gangue mineral with calcite and quartz in silver-bearing veins in the Thunder Bay area. The largest of these veins was on McKellar Island 30 km south of the city of Thunder Bay. The island is formed by a steep resistant dike of diabase which the nearly vertical vein cuts at right angles (Figure 4). The vein reaches a maximum width of 18 m and is exposed over the full width of the island, about 140 m. Although little silver was found, it was extensively explored by adit and a 40 m shaft, and subsequently was quarried for barite from 1885 to 1894. The deposit consists of about equal portions of coarse white barite and calcite (Photo 3), and hand-cobbing was used to improve the grade of barite shipped.

Photo 2 The Tionaga barite vein as it appeared in 1962.

Spar and Jarvis Islands

Spar and Jarvis are other islands in the chain formed by the dike of diabase that accounts for McKellar Island. They lie west of McKellar and about 37 km south of Thunder Bay. Both contain a mineralized vein of white barite-calcite-quartz, but barite averages less than 50 percent of the vein material. Both were worked from surface and underground for silver more than a century ago, but do not appear to have been worked for barite. The Jarvis vein may be as much as 250 m long and average 2 m in width; the Spar vein (Photo 4) is smaller.

Southeastern Ontario

Numerous narrow veins of pink barite are known in southeastern Ontario, cutting both Grenville and Ordovician rocks. They are briefly described by Guillet (1963, p. 24-27). In general they are too small for commercial interest, and of poor colour for filler uses.

Madoc

Ontario's major production of fluorspar has been from veins in the Madoc area where several dozen small mining operations are recorded during the period 1905-1961. Green fluorite, pink barite and white calcite are the

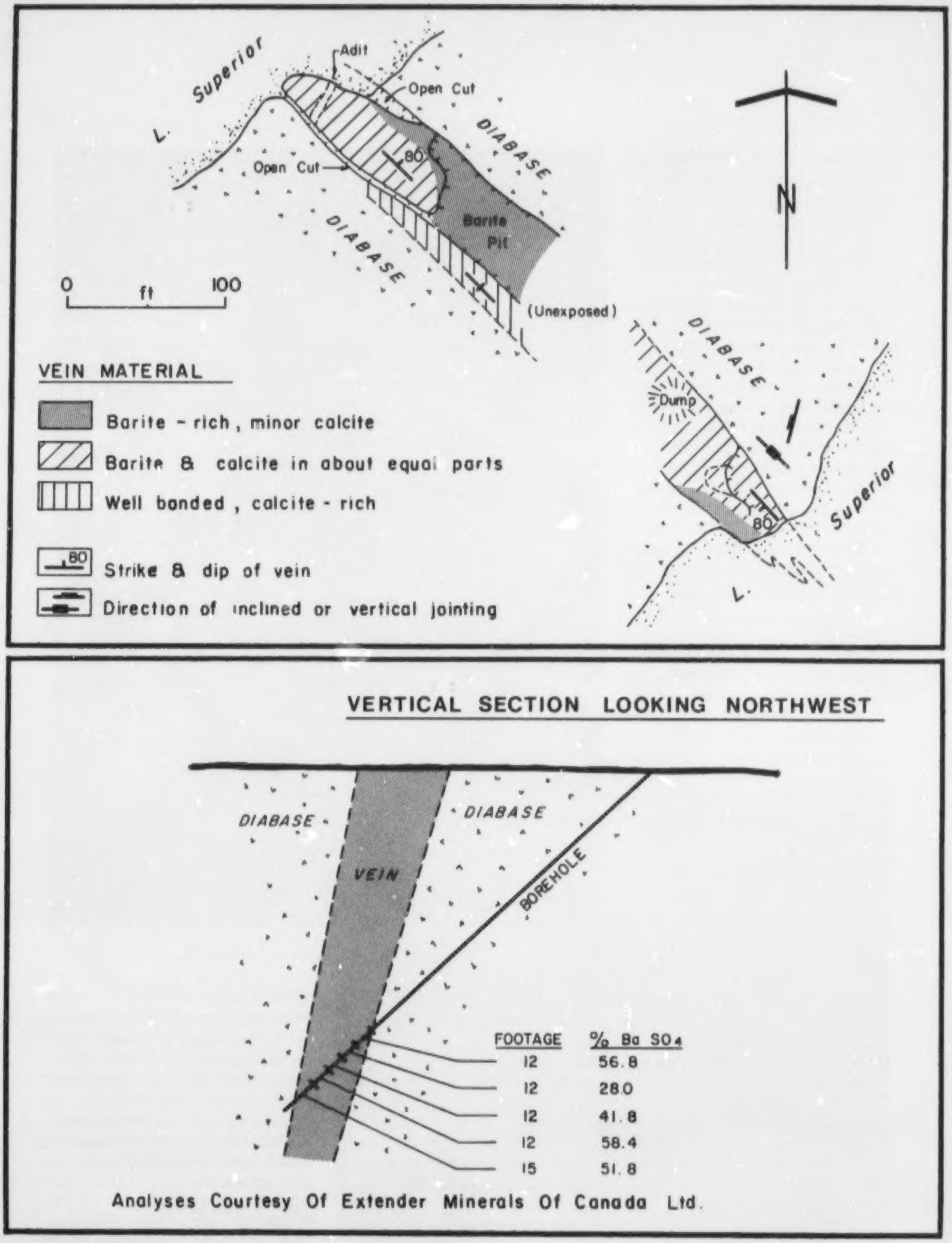

L. Superior
Adit
Open Cut
Open Cut
DIABASE
DIABASE
80
Barite Pit
(Unexposed)
0 ft 100
N
DIABASE
Dump
80
Superior
L.
VEIN MATERIAL
▨ Barite - rich, minor calcite
▨ Barite & calcite in about equal parts
▥ Well banded, calcite - rich
Strike & dip of vein
Direction of inclined or vertical jointing
VERTICAL SECTION LOOKING NORTHWEST
DIABASE
DIABASE
VEIN
BOREHOLE
FOOTAGE
% Ba SO4
12 56.8
12 28.0
12 41.8
12 58.4
15 51.8
Analyses Courtesy Of Extender Minerals Of Canada Ltd.

FIGURE 4

The McKellar Island Barite Vein

Photo 3 McKellar Island; coarse platy barite and blocky calcite.

Photo 4 The Spar Island barite vein, Lake Superior.

main constituents of veins which occupy, or are related to, the Moira Lake fault. Individual veins vary in width to 5 m and to 250 m in length. Barite is more common in veins south of Moira Lake, comprising as much as 50 percent and typically interlayered with fluorite and calcite. More detailed descriptions are available (Guillet 1964).

British Columbia

Parson and Brisco

Mountain Minerals Company Ltd. produces barite from underground mines at Parson and Brisco in southeastern British Columbia, and recovers barite from lead-zinc tailings at the Mineral King mine near Invermere. All the company's production is processed at their grinding plant in Lethbridge, Alberta.

Grey-white fine grained barite comprises more than 90 percent of the Brisco vein material in a vein up to 12 m wide and 250 m long. It has been in continuous production since 1945, first by open cut and subsequently by underground workings accessible by adit and declines. In recent years the mine has produced as much as 10,000 tonnes annually for use in drilling muds in Alberta oil fields.

The Parson barite deposit consists of two veins, the westerly being up to 9 m wide and 60 m long, and the east vein of similar width and 150 m in length. These veins also are more than 90 percent pure, and are being worked by underground methods.

Invermere

Mountain Minerals Company Ltd. has also recovered barite from the tailings of the Mineral King base metal mine. The mine was operated from 1954 to 1967 during which time it produced a small amount of byproduct barite. However, since 1970 Mountain Minerals has recovered about 136,000 tonnes of barite from the mine tailings, but this source is now almost depleted.

Spillimacheen

Baroid of Canada Ltd. has produced barite from base metal tailings at the Silver Giant mine 10 km northwest of Spillimacheen in southeastern British Columbia. The mine was operated for lead and zinc from 1951 to 1957. Baroid has recovered barite from the site since 1958, treating the tailings in a table concentrating plant.

Baroid relies mainly however on imported barite for its grinding facility at Onoway, Alberta.

Northeastern British Columbia

Large bedded barite deposits, some associated with lead and zinc, occur in northeastern British Columbia and the Yukon. Some are reported to consist of white crystalline barite. Massive beds of barite up to 30 m thick and containing millions of tonnes are known (Z.D. Hora, personal communication). None are as yet in production.

United States Producers

In 1981 there were 38 operating barite mines in 8 states (Figure 3). There were also 58 barite grinding mills in 14 states for the grinding of both domestic and imported barite (Table 4). Grinding plants are concentrated in

Table 4 U.S. Barite Mines and Mills, 1981

	Mines	Grinding Mills
Arizona	1	1
Arkansas	1	2
California		3
Georgia	2	2
Illinois	2	2
Kansas		1
Louisiana		13
Missouri	10	4
Montana	1	1
Nevada	20	6
Oklahoma		4
Tennessee	1	1
Texas		12
Utah		6
	38	58

Sources: Ampian and Morse 1982, p.3.
Watson 1982, p. 51.

the major oil states of Texas and Louisiana for the drilling mud market.

The bulk of U.S. barite production (87 percent in 1981) comes from the bedded deposits of Nevada. Residual deposits in Missouri are next in importance. In Illinois, barite is produced as a coproduct of fluorspar mining.

Nevada

Barite is widespread in black bedded deposits of Paleozoic age in Nevada. In 1981 there were 20 operating quarries, mostly in the Shoshone Range in Lander and Eureka Counties. Although deposits are lenticular, and as much as 30 m thick and 97 percent pure, they are thought to be sedimentary in origin, formed by chemical processes during deposition of the enclosing sedimentary sequence. Principal impurities are quartz and several percent of black organic matter (Brobst 1975, p. 431).

Similar deposits are mined in Arkansas and formerly also in California.

Missouri

Residual deposits of commercial value occur in unconsolidated clay beds, the result of weathering of Cambrian and Ordovician limestones and dolomites. Numerous pits are worked in southeastern Missouri; also in the Sweetwater district of Tennessee, and at Cartersville, Georgia. In 1981, ten pits were active in Missouri, two in Georgia, and one in Tennessee.

Individual deposits in Missouri may cover a large area, but this typically comprises a number of rich streaks, 3 to 6 m wide and 60 m long and containing as much as 25 percent barite, in a general background of less than 10 percent. The barite is generally white and the clay red. Lumps of barite 3 to 15 cm in size and botryoidal in shape are typical. Fragments of chert, quartz, sulphide minerals and incompletely weathered rock are also present. In Missouri, deposits are seldom thicker than 5 m, but in Georgia they may be nearly 50 m (Brobst 1975, p. 430). Bedrocks of limestone and dolomite typically contain narrow veins and pods of barite, often with fluorite, calcite, quartz and sulphide minerals. Ribs and pillars of more resistant bedrock may extend into or through the residuum.

Mining Methods

Barite mining, whether on surface or underground, uses conventional equipment and techniques. Residual deposits and most bedded deposits in the United States are worked by open pits and quarries. Vein deposits may be initially developed as open cuts, but in many cases are ultimately worked underground.

In mining residual deposits it is only necessary to scrape away the topsoil before excavating the deposit with power shovels, draglines or front-end loaders. The residuum containing the barite lumps is trucked to a washing plant where the lumps are broken down by rotary breakers and high pressure water jets. Barite, because of its softness, is more easily broken down than lumps of chert and quartz; the latter are removed by coarse screening while the clay is washed away from the barite. Final barite concentration is usually effected by jigging.

Bedded deposits in Nevada are quarried by conventional methods, except that blasting is not always necessary because of fragmentation resulting from intense structural deformation. The large deposits at Walton, Nova Scotia, and Magnet Cove, Arkansas, were developed initially by quarrying, but subsequently by underground mining. Both shrinkage-stoping and block-caving methods have been used. Originally shipped as mined, without beneficiation, the Walton barite was up-graded by heavy-media separation and jigging in later years. Magnet Cove barite is beneficiated by jigging and flotation.

Barite production in Ontario has been small and exclusively from veins. Vein deposits are mined by open cut or by shrinkage-stoping from adits or underground levels. Although veins usually form a sharp contact with their walls, hand-sorting is customary to remove wallrock fragments. Jigging or tabling may be necessary if the vein is not naturally of high purity.

FLOWSHEET : BARITE CONCENTRATOR
MOUNTAIN SPRINGS, NEVADA

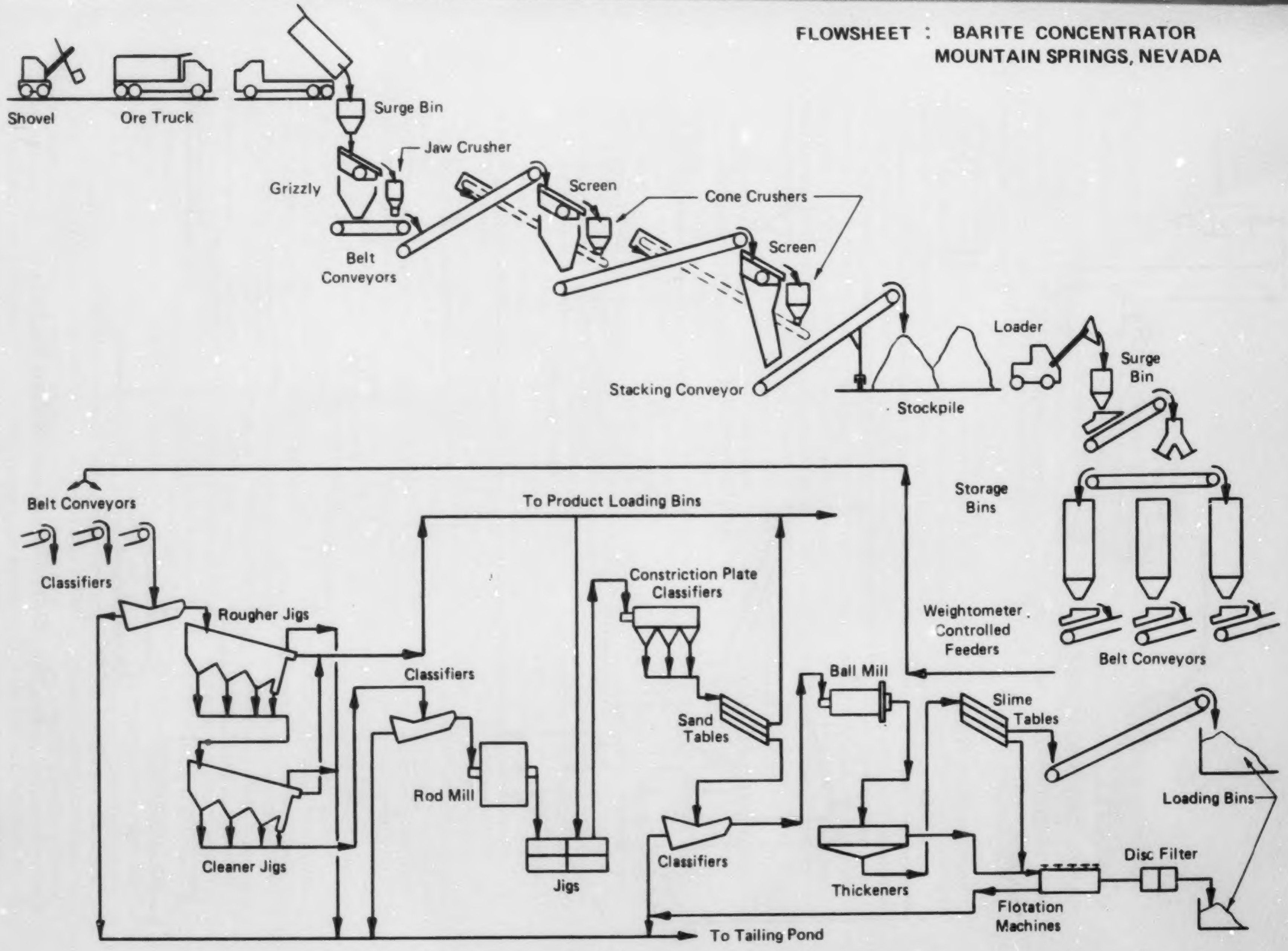
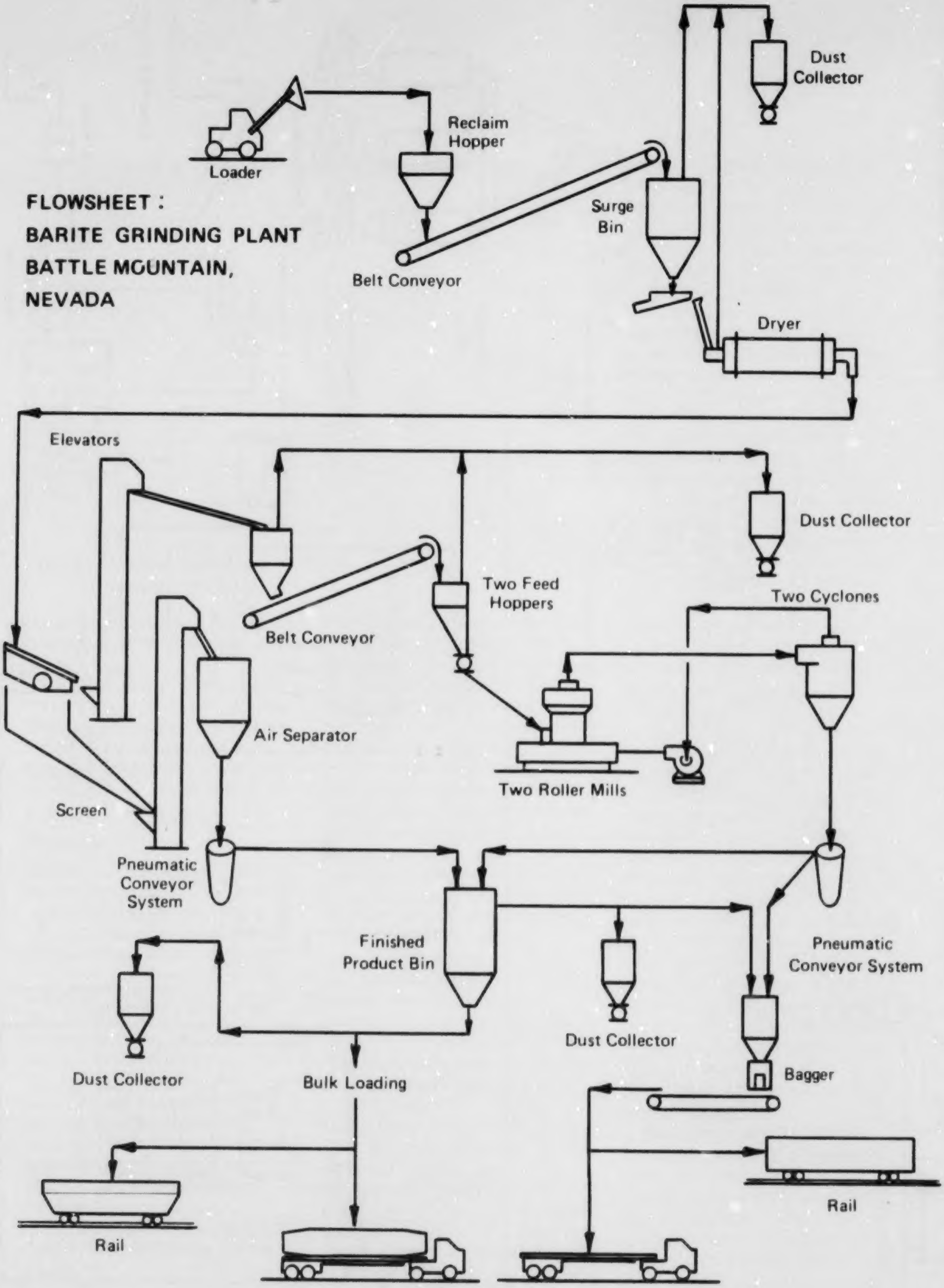


FIGURE 5 SOURCE : ENGINEERING AND MINING JOURNAL



FLOWSHEET :
BARITE GRINDING PLANT
BATTLE MOUNTAIN,
NEVADA

SOURCE : ENGINEERING AND MINING JOURNAL

FIGURE 6

Processing Technology

Barite can be processed by several methods, with the process selection largely dependent on the type of deposit and products desired. Barite is often found as a gangue mineral for lead, zinc and silver or in association with fluorite and calcite. In such instances barite may be recovered as a by-product or coproduct, or recovered from tailings at a later date. Most common commercial sources for barite however, are replacement deposits in limestone or shale and weathered residual deposits.

Primary Processing

Because of its high specific gravity, barite can be separated from associated minerals by such techniques as tabling, jigging, spiral separation and flotation. The selection of the separation process is dependent on the grade or raw material, its composition, and the quality of barite product required. Grinding is usually necessary prior to separation to liberate the barite from associated minerals.

Processing requirements for production of filler and chemical grade barite is dependent on the purity of the raw material. Barite from vein deposits may only require hand cobbing or sorting prior to grinding; or it may require upgrading by tabling, flotation or other suitable processes. Barite associated with fluorite is separated by jigging, spiral separators, tabling or froth flotation; froth flotation is commonly employed when the barite or gangue minerals are finely disseminated.

Recovery of barite from residual deposits can often be accomplished by washing in log washers to remove clay from the lump barite. This can be followed by flotation or tabling to recover any barite contained in fines from the washing operation. The lump barite is then ground and further processed if required.

Bedded barite deposits can be upgraded to commercial quality by crushing and grinding, followed by tabling or flotation. High grade barite, meeting density and solubility specifications for drilling mud grade, is ground in roller type mills. Ball mills can be used if contamination with metallic iron is not critical. Lower grade barite will require beneficiation by tabling, jigging or flotation. Barite for filler applications or feed stock for the production of barium chemicals is usually wet or dry ground, depending on raw purity and the subsequent beneficiation process to be used. A possible exception to this is the treatment of high purity barite from vein deposits; barite of high purity and natural whiteness may be dry ground after crushing, and air classified to produce filler and chemical grades.

Barite to be used in most filler applications must be of high brightness. It must be finely ground and classified to exacting particle size. Wet or dry grinding is employed in the production of filler grades. Most barite, even after benefication to improve purity, is deficient in brightness. To improve brightness, barite is bleached by leaching with sulfuric acid. The best leaching conditions and the particle size at which the bleaching is most effective must be determined experimentally.

Fine Grinding

Grinding of filler grade barite may be dry, using roller, ball or pebble mills followed by air classification to obtain products with the desired particle size. Barite beneficiated by wet processing (i.e. flotation or tabling) may be ground and classified using hydrocyclones or classifying centrifuges. Drying by rotary, flash or fluid bed dryers may be followed by further dry grinding and air classification.

Barite used for conversion to barium chemicals must have high chemical purity: Lump barite must contain a minimum of 92-96% barium sulfate ($BaSO_4$) while floated grades should have a 96-98% barium sulfate content. The product must have less than 0.5% calcium fluoride (CaF_2), 2% strontium sulfate ($SrSO_4$) and 1.0% ferric oxide (Fe_2O_3).

Only deposits of high natural purity are suitable for production of filler and chemical grades. There are only a few producers of high grade barite in the United States and Canada. Producers of filler grade barite usually also produce feed stock for the production of barium chemicals.

Uses, Specifications and Prices

Oil and Gas Well Drilling Muds

The most common use for barite is as a weighting agent for drilling muds used in oil and gas well activities. The principal function of barite in drilling mud is to suppress high formation pressures and so prevent costly and dangerous blow-outs. The most criticial specifications are: Minimum specific gravity of 4.2; free of water soluble salts; ground to 90-95% finer than 325 mesh (44 micron). Chemical purity is not critical. Specifications for drilling mud barite are covered by standards set out by the Oil Companies Materials Association (O.C.M.A.) and the American Petroleum Institute (A.P.I.).

World trade and market for barite used in drilling muds, and a listing of barite producers and processors, is discussed by I. Watson (1982, p.21-57).

Barium Chemicals

The major non filler application of high purity barite is the production of barium chemicals such as barium carbonate, barium chloride, barium hydroxide and nitrate. The processes used in the production of barium chemicals are described by J. Massonne (1982, p.65).

Table 5 Major Non Filler Applications For Barite

Application	Function	General Specifications
Gas & Oil Well Drilling Mud	As a weighting agent to suppress formation pressures and prevent blowouts of gas and oil.	Minimum specific gravity of 4.2; free of soluble salts; 90-95% finer than 325 mesh (44 micron).
Barium Chemicals	As feed stock for production of barium chemicals.	Minimum 90-96% barium sulfate ($BaSO_4$); maximum of 0.5% calcium fluoride (CaF_2), 2% strontium sulfate ($SrSO$ 4), and 1% ferric oxide (Fe_2O_3).
Glass	As a fining agent and for scum control in container glass.	Good chemical purity. Minimum 96% $BaSO_4$ and maximum 0.20% Fe_2O_3; sized $-30+150$ mesh.
Concrete	As aggregate in concrete for nuclear shielding.	High density lump barite.
Heavy Media Separation	As part of the high density media in the recovery of aluminum from non ferrous metals in scrap metal reclamation.	Granular material of high specific gravity.

Glass

Barite is sometimes used in the making of glass. Sulfates in the form of sodium sulphate, calcium sulphate or barite (barium sulphate) are added to glass batches to aid in melting, fining and in controlling the silica scum forming on the surface of the molten glass. The choice of additive is usually based on costs; gypsum (calcium sulphate) or salt-cake (sodium sulphate) is usually lower priced. Barite is considered by some glass makers to be the most effective ingredient. Its high cost is a deterrent to its more general use except in those areas where glass plants are located near a barite source.

Glass grade barite must be at least 96-98% barium sulfate ($BaSO_4$); a maximum of 0.2% ferric oxide (Fe_2O_3), 1.5% silicon dioxide (SiO_2) and 0.15% aluminum oxide (Al_2O_3). Particle size distribution should be between 30 and 150 mesh.

Other Non Filler Uses

Barite can be used as an aggregate in high density concrete for radiation shielding: Barite absorbs gamma radiation, reducing the requirement for lead shielding.

Filler Applications

Paint

The major filler use for barite is in paints. Barite is a chemically inert mineral and is used in paints requiring good resistance to acids or alkalis. Barite has a natural low oil absorption, resulting in low binder demand. It has excellent wetability in oils and good particle packing, resulting in dense chemical resistant coatings.

Barite is a relatively soft mineral with a hardness of 2.5 to 3.5 on Mohs' scale. The softness, high density, inertness and excellent sanding properties make barite an ideal pigment for automotive and industrial metal primers. Primers containing barite provide a dense paint film with good adherence and gloss.

Barite is used as a pigment extender in floor enamels. Its low oil absorption, high density and chemical inertness contributes to paint films with good wear and chemical resistance.

Barite is also used in water based semi-gloss exterior paints, particularly where a dense inert paint film with good weathering and caulking properties is required.

Natural wet or dry ground barite of low to medium brightness is used in metal primers, while chemically bleached barite is used in trade sales paints. Bleaching may not be required if the crude barite is of high purity and has a natural white colour.

Plastics

Plastics are the second largest filler application for barite. Its major use is as a filler in polyurethane foams, used in furniture, bedding and other cushion materials. Barite increases foam density, improves flexibility, tensile strength and resilience. Minor amounts of barite are used in polyethylene. Finely ground barite of medium brightness is used in foams, while high brightness barite is used in polyethylene. Barite is a functional filler, improving overall product quality, while reducing the cost of the product.

Rubber

Barite is used in the white sidewalls of automotive tires, sporting goods such as basketballs and balloons. Barite improves the elasticity of rubber. High brightness bleached grades of barite are generally used in these applications.

Carpet Backing

Barite is employed as a filler in the foam backing of automotive

Table 6 Primary Uses For Barite Fillers

Application	Function	General Specifications
Trade-Sales Paints	To provide a high density inert paint film.	High brightness; controlled particle size, low oil absorption, chemically bleached grades are commonly used.
Industrial & Automotive Primers	To provide dense inert paint films with good sanding properties.	Medium brightness; fine particle size; low oil absorption.
Plastics	As a filler in polyurethane foams, used in furniture and bedding; also in automotive carpeting as foam backing. Minor uses in polyethylene and chemical resistant vinyl floor tile.	Medium Brightness, natural barite. High brightness or bleached grades used in polyethylene and vinyl tile. Medium to fine particle sizes.
Rubber	Used in white side-walls of automotive tires, and in sporting goods.	High brightness; fine barite, low abrasiveness.
Putty Caulk and Sealants	To provide density and chemical inertness.	High brightness natural or bleached barite of fine particle size.
Carpet Backing	To increase foam density and sound deadening.	Medium brightness, medium fine barite.

carpets. It increases foam density and weight, and increases its sound deadening capacity. Medium to fine barite, with a 10 to 15 micron average particle size, is used in this application. Lower brightness grades of barite are acceptable.

Putty, Caulks and Sealants

Barite is used in liquid sealants and caulks. It contributes high density and chemical resistance to these products. In automotive vinyl sealants, barite improves the sound deadening qualities. Low cost, medium to fine barite of low brightness, to very fine expensive high brightness barite, is used in these applications. Barite is a minor filler in putty, caulks and sealants.

Adhesives

Filler grade barite is used in small quantities in the production of phenolic abrasive adhesives. The barite is added to increase density.

Prices of Filler Grade Barite

Paint extender grades of barite are priced at approximately U.S. $275 per tonne packed in 22.7 kg multi wall paper bags for natural unbleached grades; and U.S. $500 for the high brightness very fine bleached grades. Typical brightness of paint grade barite is 70 to 80 for natural unbleached, and 92 to 94 for the bleached grades.

The particle size of paint extender grades range from a mean particle size of 1.6 to 8.5 micron, with a corresponding Hegman fineness of grind of 4 to 6.5

Coarser 12 micron sizes of medium brightness barite used in carpet backing and other non critical colour applications is priced at U.S. $170 per tonne in 22.7 kg bags.

Low brightness, unbleached, finely ground and classified barite of 2.5 to 5 micron average particle size is marketed at prices ranging from U.S. $250 to $275 per tonne in 22.7 kg (50 lb) paper bags, f.o.b. point of shipment. A natural, wet ground, 1.5 micron average particle size product is priced at U.S. $320 per tonne in 22.7 paper bags.

Specifications for exterior pigment grade barites are covered in the American Society for Testing and Materials (A.S.T.M. D602-42).

Specifications of barite fillers are usually negotiated by the producer and buyer.

Production and Consumption

Estimated world production of barite in 1981 was 7.9 million tonnes, of which the United States produced 33 percent and imported 22 percent of the total. China, the U.S.S.R., Peru, India, Morocco and Mexico were other significant producers (Ampian and Morse 1982).

Production of barite in Canada in 1980 was valued at $4,380,000. For many years Canada was a major exporter to the United States, but largely as a result of the closing of the Walton deposit in Nova Scotia only 645 tonnes valued at $212,000 were exported in 1980. Imports, mainly from the United States, amounted to 45,157 tonnes valued at $4,215,000 (Vagt 1983).

Production of barite in the United States in 1981 was a record 2.58 million tonnes valued at U.S. $102 million. The bedded deposits of Nevada accounted for 87 percent. Imports, largely from China and Mexico, amounted to 1.75 million tonnes (Ampian and Morse 1982).

More than 90 percent of Canadian consumption of barite was for drilling mud in 1979; an estimated 91,992 tonnes was

Table 7 Estimated Barite Filler Market, 1980-1985

	TONNES ANNUALLY	
	TOTAL CANADA AND UNITED STATES	STUDY AREA
Paint	42,000	30,000
Plastics	16,000	6,000
Rubber	4,000	2,000
Carpet backing	2,000	200
Putty, caulks, sealants	500	300
	64,500	38,500

used. Filler uses (mainly in paint, varnish and rubber) consumed 4,323 tonnes (Vagt 1983).

Consumption of barite for drilling mud in the United States in 1981 was 4,159,000 tonnes, 97 percent of total consumption Filler uses consumed 78,000 tonnes valued at U.S. $12,807,000 (Ampian and Morse 1982). Georgia, Missouri and Tennessee were the principal U.S. sources of filler and chemical-grade barite.

Total barite market for fillers in the study area, and for all of Canada and the United States, is estimated in Table 7.

Competitive Materials

The use of barite is primarily because of its weight; it is uniquely heavy for a non-metallic mineral in reasonably common distribution. Therefore it has few competitors.

Largely because of price, calcium carbonate is being substituted for barite in some paint and plastics applications even though the end product is less desirable. Blanc fixe, an artificially precipitated barium sulphate of uniformly fine particle size, used to compete in paints but is now all but withdrawn from the market because of cost.

Various heavy metallic compounds such as magnetite, galena, and calcined pyrite (commercially called Fer-O-Bar) have been considered as substitutes for barite in drilling muds. However, they have generally proved to be more abrasive, more expensive and more difficult to handle.

Trends

The demand for barite is determined by the scale of oil exploration, and there is little doubt that this will continue at high levels for the foreseeable future. No substitute poses a serious threat to barite's use as a weighting agent in drilling muds. However, there is an increasing trend by oil companies towards recovering used drilling muds for re-use.

Barite's use as a filler and for barium chemicals is not expected to show major growth principally because of its relatively high price; calcium carbonate is increasingly assuming its place in paints. A switch from conventional spray painting to electrodeposition of automobile primers is resulting in the use of significantly less barite-based paint for this purpose.

The use of barite in plastics as a weighting agent in polyurethane foam and mineral impregnated polypropylene fibers is also threatened by its high cost, though moderate growth is expected.

In general, consumption of barite as filler has been in decline for more than a decade.

Future sources of barite are expected to continually favour bedded deposits over vein and residual types. Bedded deposits tend to be large and readily amenable to large-scale, low-cost operations. However, in general, bedded deposits have failed to provide barite of good colour (ie. whiteness) for filler markets. Hence veins and residual deposits of white barite may have a continuing need on a modest scale.

It is expected too that the recovery of barite from base metal ores and the reworking of mine tailings will continue to be attractive for drilling mud markets.

5 Carbonates

Summary

No other industrial mineral is as widely used in such a diverse range of industrial applications as calcium carbonate; nor are there many that occur in such a variety of physical forms. Limestone is its most common form, and crushed limestone is extensively used as a construction aggregate and in the making of lime and portland cement. Marble is the recrystallized metamorphic product of limestone; it can be found in an infinite variety of colour, and it enjoys extensive use as a building stone and decorative stone. Marbles which are white and of high chemical purity are particularly valuable as mineral fillers. Calcium carbonate also occurs as veins of pure calcite or in association with other vein minerals. Marl is a soft calcium carbonate mud of Recent origin, and is still in the process of being formed in many Ontario lakes.

Calcite ($CaCo_3$), the most common mineral form of calcium carbonate, is the principal constituent of most carbonate rocks. However, magnesium carbonate ($MgCO_3$) may also be present to a greater or less extent in the form of dolomite. Dolomite is both a mineral name and a rock name. As a mineral, dolomite has the composition $CaMg(CO_3)_2$. If a limestone contains significant amounts of magnesium carbonate it may be referred to as dolomitic limestone; and if it approaches the composition of the mineral dolomite, the rock may also be called dolomite although there is a trend to the use of the term "dolostone."

Carbonate rocks are the most widely mined rocks in North America. Within the study area, more than 500 companies operate some 1,500 limestone or dolostone quarries principally for construction aggregate. Few of them are capable of producing anything more than the most basic, low-priced mineral filler. Deposits of white, high-purity marble are scarce, but they are the most common sources of carbonate mineral fillers.

Carbonates, particularly the calcitic variety, are extensively used as a paper filler, and in paints, linoleum and rubber. Important properties of filler-grade carbonate include whiteness, fineness, freedom from grit, low oil absorption and equidimensional particle shape. Its relatively low cost and widespread occurrence are also major reasons for its extensive utilization.

Steep Rock Calcite, a division of Steep Rock Resources Inc., is the major commercial producer of filler-grade calcium carbonate in eastern Canada. It has large reserves of calcitic marble of high purity and whiteness which it quarries near Perth in southeastern Ontario.

Previous attempts to produce filler grades of calcium carbonate from other Grenville deposits, as well as calcite veins and marl beds, have generally been unsuccessful.

While quarrying is the most common mining method, at least three major filler producers in eastern United States operate underground mines. Processing may be simply dry grinding and air classifying, or it may involve flotation, wet grinding and spray drying.

High purity white dolomite could substitute for calcium carbonate in most filler uses, as it commonly does in Europe, but North American preference has rather arbitrarily favoured calcium carbonate almost exclusively.

Estimated annual consumption of carbonate fillers in the study area is 830,000 tonnes, largely for putty, caulks and sealants (especially drywall compounds), plastics, paint, paper and rubber.

Geology and Ontario Occurrences

Important sources of carbonates in Ontario include limestone, marble, marl and vein deposits.

Limestone dust, a product of the quarrying and processing of stone for lime, cement or construction aggregate, may be used as an inexpensive filler in asphalt and other applications where colour is not important. Both marl and vein calcite have been used for fillers on a small scale, but none are being used in Ontario today.

Marble is the principal source of filler-grade carbonate in Ontario, and it has the greatest potential for the making of fillers of high purity and value. Marble in Ontario is virtually restricted to the southern portion of the Grenville area of the Precambrian Shield.

Grenville Marble

The Grenville Province occupies the southeastern part of the Canadian Shield and is characterized by crystalline rocks with metamorphic imprints of about 950 million years. In Canada the Grenville is restricted to southern Ontario, Quebec and Labrador. In Ontario it is bounded on the north by the Grenville Front, a linear tectonic feature that is a metamorphic transition zone or fault that lies south of Sudbury and north of North Bay. Southward, Grenville rocks are found in the Adirondack Mountains of New York, the Green Mountains of Vermont, and the Precambrian highlands of northern New Jersey, southern New York, and southeastern Pennsylvania.

Two major sequences of stratified rocks are recognized in the Grenville of Ontario (Lumbers 1980). An older sequence of clastic siliceous metasedimentary rocks comprises the Ontario Gneiss Segment, outcropping in the northwest portion of the Grenville region. A younger accumulation of stratified rocks known as the Grenville Supergroup occurs in southeastern Ontario. The Grenville Supergroup is separated from the Ontario Gneiss Segment by an unconformity, and is particularly distinguished from the older gneisses by an abundance of marble (Figure 7).

Grenville marble consists of calcitic and dolomitic units of varying thickness and purity, generally trending northeast. Most marble belts are one to three kilometres wide and ten or more kilometres long (Vos and Storey 1979). Quartzofeldspathic gneiss and metavolcanic rocks are commonly associated with marble. All are complexly folded and recrystallized as a result of the Grenville Orogeny.

Grenville marbles are derived from limestones and dolostones of varying purity. Most tend to be calcitic with at least 5 percent siliceous impurities. Phlogopite, graphite and quartz are the most common mineral impurities; chlorite, pyrite, apatite, titanite, tremolite and garnet are also found. Oriented flakes of phlogopite or graphite may give the marble a thinly layered appearance, and finely disseminated graphite may impose an overall blue or grey colour.

High purity marble is distinguished by its whiteness and obvious lack of mineral impurities. An effervescent reaction to a drop of dilute hydrochloric acid administered from an eye-dropper is a good field indication of calcitic composition. Pure marbles, particularly calcitic ones, are often poorly exposed because they are generally most easily weathered and eroded. Also, thin beds of amphibolite and quartzite interlayered with the marble may limit its mineability.

In 1977, William R. Barnes Limited commenced production of white calcitic marble near Perth in southeastern Ontario. The operation was taken over by Steep Rock Iron Mines Limited (now Steep Rock Resources Inc.) in 1980.

Prior to the successful production of calcium carbonate fillers at Perth, a number of marble deposits had been investigated in widely scattered parts of Ontario's Grenville area.

Belmont Township

White, pink and grey marbles, both calcitic and dolomitic, occur on a property owned by Northumberland Mines Limited. Three zones of white calcitic marble have been delineated by several drilling programs directed by Northumberland (1975-6), Englehard Minerals and Chemicals (1977) and Preussag Canada Limited (1980). Impurities such as quartz, mica, diopside, tremolite and iron sulphides are randomly distributed, but beneficiation tests by Lakefield Research Limited and Ontario Research Foundation have been generally effective in their removal by flotation. Best results have yielded a laboratory product containing 3 percent magnesium carbonate and less than 0.5 percent silica, with a brightness value in the low 90's.

Burleigh Township

American Nepheline Limited (now Indusmin Limited) carried out a program of geological mapping, sampling, diamond drilling and laboratory testing of a marble deposit in south Burleigh Township in 1954-6. The deposit consists of coarse friable white calcitic marble with a few scattered quartz grains and minor phlogopite and diopside. Narrow granite dikes and a few thin layers of quartzite and amphibolite are undesirable features of the deposit. With these removed, the marble was low in magnesia but averaged about 6 percent acid insoluble, mostly silica. The simultaneous discovery of ancient rock carvings on the main deposit, and the impracticality of moving them resulted ultimately in incorporation of the deposit in Petroglyph Provincial Park.

Guilford Township

White dolomitic marble is quarried near the village of Eagle Lake, Haliburton County, and is processed in a crushing and screening plant on the site. Three quarries have been opened in a high ridge of medium to coarse grained marble. A few lenses and inclusions of black amphibolite cut the marble zone, and minor amounts of diopside, phlogopite, pyrite, tremolite, serpentine and actinolite are disseminated throughout. Products include poultry grit and crushed chips for decorative purposes (Hewitt 1964, p. 16-17).

Hagerman Township

In 1966-7 Cononaco Mines Limited constructed a small plant at Waubamik, 12 km north of Parry Sound, with the intention of producing calcium carbonate fillers from a small marble deposit in Hagerman Township, 20 km north of the plant. The deposit consists of impure coarsely crystalline marble interlayered with lenses of amphibolite. Although small patches of coarse white calcitic marble are scattered throughout the deposit, the marble generally has a grey to green cast due to a variety of accessory minerals, including graphite, phlogopite, hornblende, diopside and chondrodite. The deposit averages about 7 percent magnesium carbonate and 8 percent acid insoluble, mostly silica. Early plant runs without beneficiation produced unacceptable products, and although testwork indicated much improvement with combinations of electromagnetic, electrostatic and flotation equipment the project was ultimately abandoned.

Hungerford Township

In 1962-3 Vermont Marble Company carried out diamond drilling on a zone of white high purity marble south of Actinolite. Hewitt (1964, p. 53) reports that no mineral impurities were noted. The zone is 75 m wide, strikes north-south and is nearly vertical. Overburden obscures all but a small outcropping of the best rock.

Huntingdon Township

Canada Talc Industries Limited produces by-product dolomite chips and grit from its underground talc mine at Madoc. The

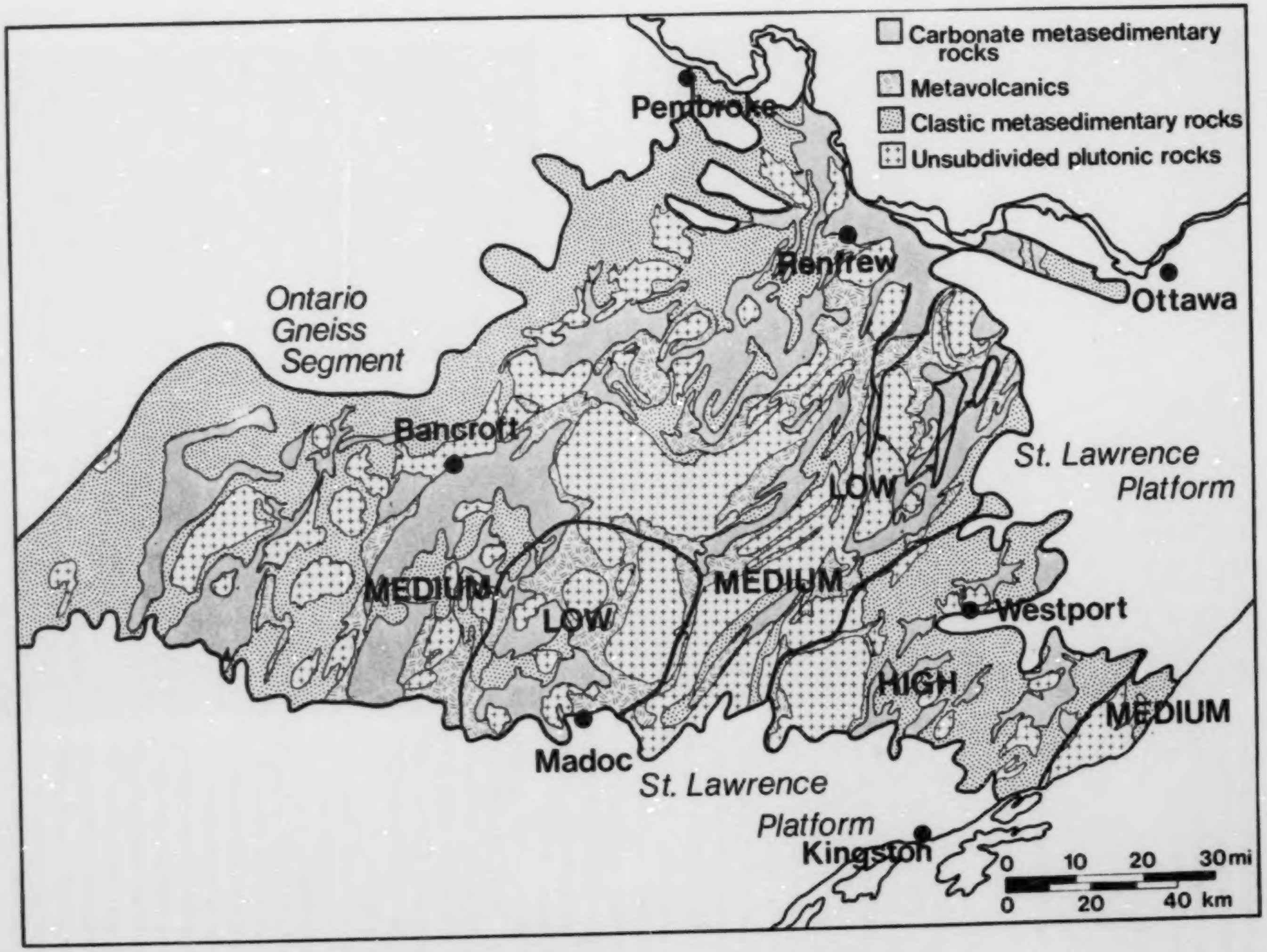


FIGURE 7 GRENVILLE MARBLES OF EASTERN ONTARIO
Showing also generalized metamorphic isograds (after Carter and Colvine 1982)

marble is white, fine-grained, and dolomitic, and contains tremolite and other silicates (Hewitt 1964, p.51).

Marmora Township

White calcitic marble was formerly quarried at Malone by W.F. Bonter Company. Six quarries were opened over a length of 1 km in fine to medium crystalline white calcitic marble. A few black amphibolite inclusions and rusty mafic dikes cut the marble. The natural quality of the marble is generally less than 3 percent each of silica and magnesia. A crushing and screening plant on the site produced man-sized stone for pulp and paper mills, terrazzo chips, poultry grit, and a dust product added to feed formulas for poultry and livestock (Hewitt 1964, p. 31-33).

Ross Township

Timminco Limited, formerly Dominion Magnesium Limited, produces calcium and magnesium metals from a deposit of coarsely crystalline white dolomite at Haley 40 km south of Pembroke. The high purity marble zone is 75 m wide, strikes north-south and dips 60° E. A few patches of grey, buff and pink marble are scattered throughout.

Spence Township

During the period 1972-5 Burcal Mines Limited attempted to produce high quality calcium carbonate fillers from its plant in Burks Falls. Some shipments were made for carpet backing and other uses where high purity was not required. The plant, which was essentially a crushing and screening plant, was not effective on the impure marble without any form of beneficiation. The marble deposit was located some 30 km west of the plant. Although coarsely crystalline it contained a considerable variety of accessory minerals.

Other white marble deposits, both calcitic and dolomitic, have been investigated from time to time as possible sources of high purity filler. Hewitt (1964) describes a number of them. Vos (1977), Vos and Storey (1979), and Papertzian and Kingston (1982) report the results of widespread marble sampling in eastern Ontario.

Marl

Marl is essentially an unconsolidated limestone; a soft white to buff limestone mud that forms the bed of certain small lakes and marshes. It is the product of biochemical precipitation induced by the process of photosynthesis in Green and Blue-green algae. In marl lakes these algae are so prolific as to give a most distinctive and attractive blue-green colour to the water.

Marl lakes typically occupy landlocked spring-fed basins close to bedrocks of limestone and dolomite. They are most abundant in southern Ontario where they are all post-glacial in age and many are still in a stage of active formation.

From 1889 to 1919 marl was used with clay in the manufacture of portland cement in Ontario. Fourteen plants in southern Ontario used marl exclusively for much of this period, but by 1919 all had either closed or converted to limestone. For cement, as for most limestone markets, marl is inferior because of its lesser purity and greater difficulty of drying.

Several attempts have been made in Ontario to produce calcium carbonate fillers from marl. Unfortunately, Ontario marls tend to contain organic matter and clay, and attempts at commercial utilization were generally short-lived.

Descriptions of many marl deposits, and preliminary assessment of their compositions and filler properties, are given by Guillet (1969). Two deposits which were worked for a short time for filler purposes about 1940 are described in the following notes.

Harvey Township

Marl underlies a shallow lake and marsh in the northwest part of Harvey Township, 10 km north of Bobcaygeon. About 5 m of marl occurs in the bed of the lake near its centre. The marl is of good chemical quality but is pale brown or grey due to finely divided organic matter. The marl bed occupies an area of at least 18 ha.

The deposit was acquired in 1934 and was successively worked by White Valley Mines Limited, White Valley Chemicals Limited, and Chem-Ore Mines Limited. A small plant to produce 50 to 70 tonnes per day was erected on the site; it used banks of infra-red lamps for drying (McLaren 1945). The only recorded production was 800 tonnes in 1940 (Satterly 1943, p.55).

A small area near the site of the plant contains a shallow deposit of dense white marl that may have been a stockpile of dredged material that has been improved by some form of beneficiation, if only by natural washing. It contains about 1.5 percent magnesium carbonate and less than 0.5 percent acid insoluble; particle size is 94 percent finer than 325 mesh, 75 percent finer than 10 microns (Guillet 1969, p.95-97).

Photo 5 is a vertical aerial view of the deposit.

Hungerford Township

One of the best quality marl deposits underlies Dry Lake and nearby marshes at Marlbank, 25 km north of Napanee. Dry Lake marl was dredged for two cement plants, at Marlbank and Strathcona, during the period 1891-1914. In the 1940's the Ontario Paper Company used Dry Lake marl as a substitute for English chalk for paper filler. Photo 6 is a verticle aerial view of Dry and Lime lakes.

The marl bed covers an area of 90 ha, about half of which is undisturbed by earlier dredging, and the bed is 3 m to 4 m thick.

In 1965 thirty auger holes were drilled on the west shore at 30 m intervals. Analyses of these

Photo 5 White Valley deposit, Harvey Tp., Peterborough Co. In 1940 a small amount of marl was produced for filler purposes in the plant at the southeast end of the deposit. North is to the top.
Courtesy Ontario Ministry of Natural Resources, Air Photo Library

Photo 6 Dry and Lime Lakes, Hungerford Tp., Hastings Co. Dry Lake was dredged by a succession of cement companies, 1891-1914. It was also taken from a small area at the south end, between the roads, as a substitute paper filler in the 1940's. North is to the top.
Courtesy Ontario Ministry of Natural Resources, Air Photo Library

samples showed the marl to contain negligible amounts of magnesia and almost no silica. Dry brightness is about 80 and oil absorption 45. Average particle size is 86 percent finer than 325 mesh, 63 percent finer than 10 microns (Guillet 1969, p. 65-68).

Vein Deposits

Calcite is a common constituent of veins, where it is often the host for sulphide minerals or occurs with other vein-forming minerals such as quartz, barite and fluorite. Crystallization in veins is usually very coarse and the vein minerals are often of high chemical purity. Rarely, however, do veins of pure calcite occur in sufficient size to be of interest as sources of filler-grade calcium carbonate. One such occurrence in eastern Ontario is described in notes that follow. White calcite of apparent purity occurs with barite, quartz, silver and sulphide minerals in veins of the Lake Superior region. Some of these are described by Guillet (1963). The largest one, on McKellar Island 30 km south of the city of Thunder Bay, varies in width from 10 to 20 m over a length of 135 m, and consists of massive white calcite and barite in about equal proportions. Pink and white calcite is also a major constituent with fluorite and barite in the fluorspar veins of the Madoc area (Guillet 1964).

Palmerston Township

An unusually large vein of pure calcite cuts through granite with an east-west strike and a vertical dip. It varies in width from 18 m to 30 m and has been traced by drilling over a length of more than 200 m and a depth of 45 m. The calcite is very coarse to massively crystallized and is cream-coloured to faintly pink. Except for occasional fragments of the granite wallrock near the vein contacts, the vein material is entirely calcite.

The property was acquired in 1946 by Marlhill Mines Limited, and a small mill and rail siding was constructed in 1953 at Robertsville, 3 km east of the deposit. Prior to this, lump calcite was said to have been shipped by rail to U.S. destinations for use as a paper filler. The property was acquired in 1954 by Canada Calcite Company and the mill was re-equipped for finely ground filler products. Some production was reported shipped to linoleum, putty, paint, rubber and other industries before operations ceased in 1955.

The finely ground calcite has a good brightness, contains less than 1 percent magnesium carbonate and less than 3 percent acid insoluble.

Mining Methods

Carbonate rocks are normally mined by quarrying. But there is a surprising number of underground mines in the United States, the most famous of which are those near Kansas City where effective and diverse use has been made of the mined out space (Stauffer 1976). In 1971 there were 87 underground limestone mines in the United States, accounting for about 5 percent of total limestone production (Carr and Rooney 1975, p. 772), approximately 28 million tonnes. In 1981 there were 129 producing more than 45 million tonnes (Robertson 1983, p.29).

Underground mining of carbonate rocks in the United States averages about 26 percent more costly than surface mining (Dunn 1983, p.32). Hence it is considered only in special circumstances, such as when deep quarrying of a particular deposit has reached its economic limit, or when alternative sources are not available on surface within an economic haulage distance.

Deposits of high purity calcium carbonate, because of their greater scarcity and value, are most likely to be considered for underground mining. White calcitic marble is mined underground at Tate, Georgia, by Georgia Marble Company; at Crab Orchard, Tennessee, by Franklin Limestone Company; at Texas, Maryland, by Genstar Stone Products; and Danby, Vermont, by Vermont Marble Company.

Since deposits of limestone and marble are commonly tabular in shape they are usually mined by room and pillar methods where underground mining is necessary. Access is often by horizontal tunneling into a hillside or quarry face, but inclined ramps and vertical shafts are also used.

Few limestone mines are more than 300 m deep and most are less than 100 m. The mines are well ventilated and spacious to accommodate large conventional diesel trucks and loaders. Rooms should be at least 5 m high and 10 m wide and may be as high as 25 m and as wide as 15 m. However, roofs higher than 10 m become increasingly difficult to reach for necessary rock sealing and roof- bolting. At least 25 percent of the deposit is left in the mine as pillars to support the roof.

Except where underground workings are accessible to quarry trucks via horizontal or inclined ramps on gradients of about 10 percent, primary crushing is normally carried out before hoisting to surface. In such cases the crushed rock is moved by conveyor to the shaft, or directly to surface plant or stockpile by inclined conveyor in special conveyorways at about 25 percent grade (4:1 slope).

Most deposits will be accessible to surface quarrying, where operating methods may be similar to conventional quarrying of limestone and dolomite for construction aggregate. However, because of stringent quality requirements, quarrying of high purity marble may have to be more selective to avoid zones of waste rock. It is desirable to have a number of working faces to give flexibility to the operation and permit blending where quality variations occur.

In preparing a quarry site, overburden removal must be thorough. Whether self-propelled earth movers or diesel shovels, trucks and bulldozers are initially used, final cleaning of the rock surface by pick and shovel is usually necessary. If the site is elevated and well-drained, hydraulic washing by high pressure hoses may be usefully employed for final cleaning.

Adequate definition of the limits and quality variations of a deposit is a prerequisite to effective quality control at the mining stage. Diamond core drilling at intervals not exceeding 60 m is essential. Holes should be oriented and inclined to intersect the foliation or bedding of the rock at right angles (i.e. perpendicular to the strike and dip). Cores should be split and carefully logged. One split half of the entire core should be sampled for laboratory evaluation. Individual sample lengths should be based on stratigraphy, but normally will be in the range of 3m to 12m.

Large uniform deposits may lend themselves to large-scale contract mining. Steep Rock's quarry at Tatlock is worked only for a few weeks each summer, when sufficient crushed marble is stockpiled at the Perth plant for the year's needs.

Processing Technology

Methods used in the processing of limestone or dolomite for filler applications are dependent on the mineralogical and chemical purity of the raw material and the product quality required by the consuming industries.

Ground limestone is used as a filler or extender in many industrial applications, ranging from aggregates in asphalt paving materials to finely ground, very white products used in paint, plastics, rubber and paper.

Dolomite has similar industrial applications, but North American practice has traditionally preferred calcium carbonate as the filler choice in such applications as paints, plastics and paper. This to some extent conflicts with European practice, where finely ground dolomite is used in a much broader range of filler applications.

The processing of limestone or dolomite is therefore directed towards producing products suitable for the broadest possible range of applications in keeping with the market potential in any geographic area.

To establish the processing requirements will, in the majority of cases, require a preliminary process development study. The process must be adapted to the particular mineralogical and chemical composition of the raw material. A thorough understanding of the geology of the deposit and its mineralogical characteristics is essential for achieving optimum results in such a study.

Processing plants for the production of limestone or dolomite fillers can be classified into six categories:

1. Processing plants producing aggregates and other "non-filler" type products from which the fines generated during processing are sold as low cost fillers.
2. Processing plants producing aggregates, but with dedicated facilities to produce filler products, by dry grinding and air classification. Usually these products are off color and are used in non-critical applications.
3. Processing plants dedicated to the production of high quality fillers using dry processing consisting of crushing, grinding and air classification circuits.
4. Processing plants dedicated to the production of high quality filler products using a wet beneficiation process consisting of wet grinding, flotation, and further wet grinding classification by centrifuges or cyclones followed by filtration and drying.
5. Plants combining dry and wet processing techniques with part of the product range produced by wet grinding and other products by dry grinding.
6. Processing plants producing very fine fillers using special wet grinding techniques, classifying centrifuges and spray dryers.

The first two types of plants produce fillers of lower quality from off-color limestones or dolomite. The products are sold locally, usually in such applications as roofing products, carpet backing, asphaltic sealers, putty and caulking compounds.

The third and fourth type of plants are conventional filler producers which meet the requirements of most users except those requiring ultrafine particle sizes.

The fifth and sixth type of plants produce ultrafine products of less than 5 microns particle size that cannot be effectively produced by dry processing. Recent advances in grinding technology, and the demand for finer particle sizes and greater purity, have caused some existing plants to modify their processing capability to this level.

Electronic color sorting has been successfully applied in some cases to remove "off-colour" rock or gangue minerals. It is currently being used in Finland and is under investigation by producers elsewhere.

Improved processing techniques are continually being developed, particulary in the field of fine grinding, both wet and dry, and the classification of wet and dry ground products.

Similarly, the growing demand for coated calcium carbonate using stearates or coupling agents has necessitated the development of new equipment and techniques. The degree of sophistication in processing carbonate fillers has expanded significantly over the last decade as new applications and new products are developed (Figure 8).

Continuing research in filler applications has lead to the development of "tailored products" for specific applications. The plastics and pulp and paper industries are good examples of new applications for calcium carbonate. These new developments have also generated a need for improved process and quality control systems.

Environmental aspects are an important facet of mineral processing. However, the technology and equipment for dust collection, noise suppression and waste disposal are well developed, so that compliance with environmental regulations can usually be achieved.

Crushing, Grinding and Classifying

Primary crushing is usually accomplished with jaw or gyratory crushers. Impact crushers are used in some instances where the raw material is soft and free of silica.

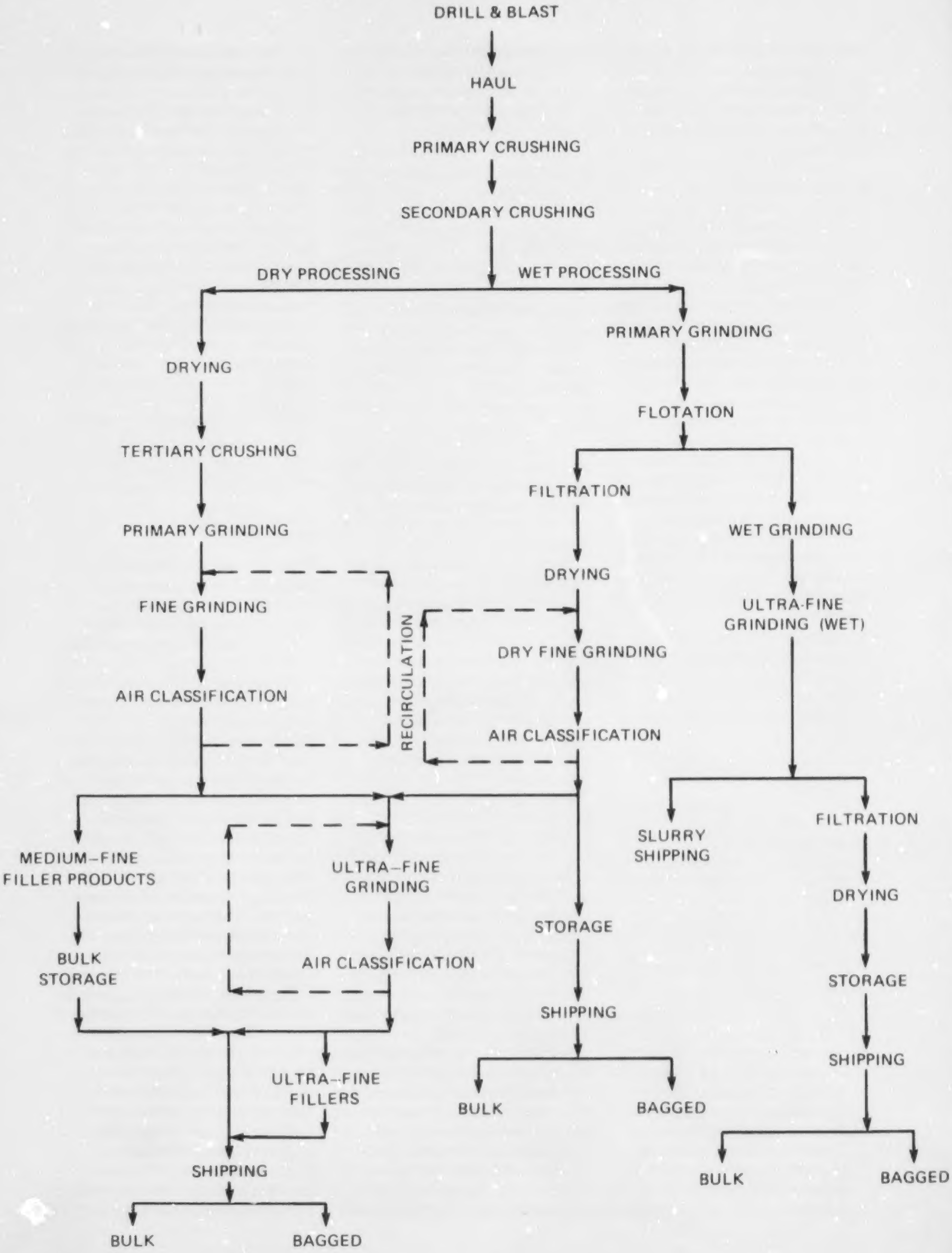
Secondary crushing is usually accomplished by cone or impact crushers. The equipment selection is based on the nature of the rock to be crushed. Secondary crushers usually operate in closed circuit with vibratory screens to provide properly sized feed for subsequent processing, or to produce granular products for non-filler applications. Autogenous or semi-autogenous milling can be used for secondary processing provided the raw material is amenable to this grinding method.

Further processing may consist of a third stage of crushing or grinding. The crushing methods available and the range of suitable equipment are broad and in general are tailored to later processing requirements.

Rolls crushers, roller mills, cage mills, rod mills and ball mills may be used, often as pregrinding units, providing feed for a fine grinding circuit or for a

FIGURE 8

CONCEPTUAL FLOWSHEET—CALCIUM CARBONATE PRODUCTION
DRY OR WET PROCESSING ALTERNATIVES



froth flotation circuit.

Subsequent processing may include fine grinding and classification. Roller mills are frequently used to produce medium to fine filler products, up to 99% passing 325 mesh (44 micron).

Ball mills, pebble mills and vibratory mills are the principal methods of fine grinding. This type of equipment usually operates in closed circuit with air classifiers, with oversize from the classifier returning to the grinding mill for further grinding. The products produced by the classifiers may be the finished products or they may be used as feed to a second stage of classification to produce even finer products. Grinding mills may range from large diameter, short length autogenous mills and conical mills to small diameter, long length tube mills. Some mills have two or more grinding compartments, separated by grates, using progressively smaller size grinding media in successive compartments. Product discharge can be by gravity or by air sweeping the mill, removing the ground material and conveying the produce-laden air to an air classifier.

The selection of the fine grinding equipment is based both on economic and technical considerations. Conventional ball or pebble mills are used to grind products ranging from 100 to 325 mesh. Vibratory mills and the newly developed agitator mills are capable of grinding to even smaller particle sizes. Dry mills can operate in open or closed circuit with air classifiers and cyclones; wet ones with classifying centrifuges.

Air classification allows production of very fine products with a top size of 8 microns (.00032"). Multi-stage classification is often employed to produce a range of fine filler products. In this process, a fine product is produced in the first classifier with the oversize directed to a second classifier to produce the next coarser product. This may be repeated several times.

Additives and Grinding Aids

While it is not common practice, grinding aids in the form of various commercial organic liquids especially prepared for the purpose may be used in the grinding of carbonate fillers. The purpose of grinding aids is to prevent formation of micro-agglomerates which may coat the grinding media and mill shell. This condition is often encountered in fine grinding. Grinding aids, if properly selected, can also improve the flow properties of the mineral and the efficiency of air classification.

For certain product applications it is advantageous to coat the filler products, and metal stearates are commonly used for this purpose. Other additives, such as coupling agents, may be used to modify the surface of the carbonate particles.

The techniques for coating or surface treatment with coupling agents are often proprietary. High speed, high intensity mixers operating in a batch configuration are popular in Europe. High speed pin mills, vibratory mills, disc mills and various "high shear" mixers are used in North America. In some instances, producers of carbonate fillers contract out their coating or other surface modification treatments to specialists.

Uses, Specifications, Prices

The commercial uses of carbonate fillers cover a wide spectrum of applications, specifications and prices.

Specifications

The most significant attributes of carbonate fillers that determine their usefulness in industrial applications are:

1. Particle size (i.e. fineness).
2. Whiteness (brightness).
3. Mineralogical and chemical purity.

Particle Size

The particle size of commercial grades of carbonate fillers covers the range from 100 mesh to less than 5 microns. Some producers offer as many as twenty products each with a different particle size distribution. In many instances the products were designed to meet the special requirements of a certain application.

Four standard grades are recognized by the American Society for Testing Materials (A.S.T.M.), or are designated by the Pulverized Limestone Association. Within each grade are a number of filler products that fall within the specifications published for these grades.

However, consumers of carbonate fillers may request specifications which differ from published standards. Such specifications are normally the result of development work, which identifies superior performance characteristics for such "non standard" products.

Research and development by producers and consumers continues to develop new products and applications for carbonate fillers. Finer products, and coated or surface modified products, have been introduced in recent years for special uses. Many of the new "superfine" fillers have been developed during this period.

The last ten years have been a period of dynamic growth in the use of calcium carbonate fillers. New applications, particularly in the plastics and paper industry have necessitated expansion and upgrading of existing plants and the development of new facilities. This trend is expected to continue.

Particle size distribution is influenced by the grinding and classification method employed. Changes in particle size distribution can cause a measurable change in product performance in some applications. The oil absorption or water demand of a filler is a function of its surface area. Packing density of the particles affects oil absorption, resin or water demand, as well as the viscosity of aqueous and organic systems. Particle size is therefore rigidly controlled at all times during production.

The standard sieve series is used to measure the particle size distribution of products coarser than 325 mesh. Products finer than 325 mesh (44 microns) or with only small amounts (10% or less) retained on a 325 mesh sieve require special equipment to determine the sub-sieve particle size distribution. Equipment suitable for this is produced by Leeds and Northrup, Coulter Counter Co., Royco Inc. and by Micromeretics Instruments Inc.

Other techniques such as the Fisher particle size analyzer are used to determine the average particle size. The Hegman gauge is used to determine the coarseness parameter i.e. the size of the larger particles in a filler product, a very important criteria.

Whiteness

Whiteness of a carbonate filler is important in applications such as paint, plastics and paper. Other applications are less demanding, allowing the use of off-white to gray products. Asphaltic roofing, asphaltic sealers, carpet backing, jointing and caulking compounds as well as some plastic applications can use off-white carbonate fillers, providing the filler complies with other specifications such as particle size, freedom from abrasive components and other performance related characteristics such as oil absorption and bulk density.

Brightness, which is largely a measure of whiteness, is expressed in a number of ways, and this may lead to slightly varying results. Therefore producers usually state on their product data sheet the method used to determine brightness. Some efforts are being made to standardize the method for brightness determinations. For example, the paper industry has published a standard test method TAPPI-STANDARD T 646 OS-75.

Mineralogical and Chemical Purity

Carbonate fillers must have a high degree of purity. Mineralogically they must be either pure calcite or pure dolomite with a minimum of contaminants. Of particular concern is the presence of quartz or other abrasive minerals. Dark minerals, if present, may affect the color of the filler and must be removed by magnetic separation, froth flotation or by electronic color sorting or manual sorting of the crude rock. Carbonate fillers should also be free of deleterious trace elements such as arsenic and lead. The water solubility of the filler should be low as an indication of a lack of water soluble salts which can cause problems in many applications.

Grade Designations

Grade designations for pulverized or ground limestone are covered by the American Society for Testing Materials (A.S.T.M.), Standard D-1199. Table 8 shows examples of typical calcium carbonate filler specifications, covering each of the four grade classes recognized by A.S.T.M.

Each of the grades covers a wide size range. Producers of calcium carbonate fillers may have as many as five products within each grade category. As a result there is a tendency to classify the various grades more closely. Kline (1978) broadens the range of grades from 4 to 8 using the following classifications:

Grade	Average Particle Size, Microns	Maximum Particle Size, Microns
1	1	10
2	3	15
3	5	25
4	10	30
5	7	44
6	12	75
7	15	150
8	17	200
*0	0.7	5

*For completeness we have added a grade 0 to cover superfine grades.

For the purpose of this report, the four-fold grade designation as provided for in A.S.T.M. D-1199 will be followed throughout.

There are no specific minimum specifications with regard to chemical composition, except that the filler should have the maximum calcium carbonate content possible. It is also most desirable to have a minimum of acid insoluble components such as quartz, silicates or other hard abrasive minerals. High brightness, in the order of 94-96 compared to a pure magnesium carbonate standard, is essential for superior grades.

More critical specifications relate to the particle size of the filler as indicated by a number of critical parameters (see Table 8):

1. Size of the coarsest particle, as determined by the Hegman gauge.
2. The mean average particle size, defined as the size at which 50 percent of the sample is coarser and 50 percent is finer. This is commonly called the D-50 point.
3. Coarseness parameter is the diameter in microns below which 99.5 percent of the particles fall.

Table 8 Grade Designations and Typical Properties of Calcium Carbonate Fillers

GRADE (ASTM–D–1199)	GRADE I	GRADE I	GRADE II	GRADE II	GRADE II	GRADE III	GRADE III	GRADE IV
PARTICLE SIZE ANALYSIS								
%Retained on 325 Mesh Sieve	0.005	0.01	0.02	0.02	0.0	1.0	1.0	22.0
Particle Size Range (Microns)	0.5-15.0	0.5-31.0	0.5-36.0	1.0-50.0	0.5	8.0	8.0	40.0
Mean Particle Size (Microns)	3.0	6.5	7.0	12.5	13.0	17.5	17.5	36.0
Hegman Grind	6-6¼	5-5¼	4-4¼	3				
PHYSICAL PROPERTIES								
Oil Absorption, ASTM-D-281 (lbs/100 lbs)	14.0-16.0	13.0-15.0	12.0-14.0	10.0-12.5				
Oil Absorption, ASTM-D-1483 (lbs/100 lbs)	15.0-17.0	13.5-15.0	13.0-15.0	11.0-13.0				
Loose Bulk Density (lbs/cu ft)	49.0	59.0	62.0	63.5	64.0	69.5	69.5	74.0
Bulking Value (gal/lbs)	0.0443	0.0443	0.0443	0.0443	0.0443	0.0443	0.0443	0.0443
Specific Gravity	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71
Specific Resistance (ohms)	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
pH	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4
Hardness (Mohs)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Refractive Index (mean)	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59
Dry Brightness (minimum)	96.0	96.0	94.0	93.0	93.0	85.0	93.0	90.0
CHEMICAL COMPOSITION								
%Calcium Carbonate (CaCo$_3$)	98.00%	98.00%	98.00%	98.00%	95.00(min)	95.00(min)	95.00(min)	95.00(min)
%Magnesium Carbonate (MgCo$_3$)	0.60	0.60	0.60	0.60	3.00(max)	3.00(max)	3.00(max)	3.00(max)
%Silica (SiO$_2$)	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00
%Iron Oxide (Fe$_2$O$_3$)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
%Alumina (Al$_2$O$_3$)	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
%Moisture (H$_2$O)	0.02	0.02	0.02	0.02	0.02	0.15	0.15	0.15

4. Particle size parameter, or equal spherical diameter, as determined by the Fisher subsieve sizer.
5. The total particle size distribution as determined by an accepted technique.
6. Oil absorption by the Rub-out or Gardner method; A.S.T.M. D-281.

In addition, filler manufacturers usually also provide data on the loose bulk density, bulking value, specific gravity, specific resistance, pH, hardness and refractive index (Table 8).

Uses

Paint

Calcium carbonate is used as an extender in oil, alkyd, acrylic and latex-based paint systems. Paint manufacturers select appropriate extenders for use in their products with particular reference to the following specifications:

Oil absorption
Hegman fineness
Particle size distribution
Whiteness (brightness)
Freedom from abrasive components, particularly silica.
pH (Hydrogen ion concentration of the filler slurried in water)
Water solubility
Chemical composition
Bulk density

In evaluating a new filler the paint chemist may prepare a variety of paint formulations substituting the new filler for the carbonate filler in current use. He then compares the properties with the paints containing the "standard" extender. Some of the properties measured are:

Viscosity at a specified pigment to vehicle ratio.
Stability and settling resistance.
Ease of dispersion in the paint vehicle.
Effect of freeze-thaw cycles on viscosity and paint stability, i.e. shelf life.
Brushability.
Scrubbability (if flat paint).
Burnishing resistance.
Sheen or gloss of prepared paint film.

In general, the paint chemist will look for a carbonate extender which when incorporated in a given paint formulation will provide paint with properties equal to or better than paints made with the standard extender. Most paint manufacturers obtain their carbonate extenders from several sources.

Oil absorption is a very critical

Table 9 Primary Uses for Carbonate Fillers

Application	**Function**	**General Specifications**
Paint	Extender of prime pigments in interior and exterior paint formulations.	High whiteness; controlled particle size, 44 microns to 8 microns top size.
Plastics	As a resin extender in a wide range of polymer systems.	High whiteness; controlled particle size, 30 to 5 microns top size; fillers treated with coatings and coupling agents are used.
Paper	As a filler or for paper coating. Partial displacement of kaolin.	High whiteness; controlled particle size, low abrasion, very fine products with top sizes ranging from 10 to 4 microns.
Putty, Caulking, Sealing		White, medium to fine, 90–99% passing 325 mesh (44 microns).
Vinyl Floor Covering	As a filler in vinyl tile	Coarse granular (– 40 mesh) to fine (– 325 mesh); good white colour; controlled particle size and bulk density.
Carpet Backing		White to gray colour; 90%–99% passing 325 mesh.
Asphaltic Products	Filler in roofing materials and asphalt sealers.	Off-color buff to gray; coarse ranging from 80% passing 325 to 80% passing 200 mesh.
Rubber	Filler pigment in footwear, automotive goods, non-reinforced rubber, wire and cable coatings.	White to off-colour; Fine to medium fine products.
Construction	Filler in jointing compounds for gypsum board.	Lower grade white products; 90–95% passing 325 mesh.
Other	Synthetic Marble	White, coarse products; 80–85% finer than 200 mesh, and granular grades.
	Coal Dusting	White to buff, coarse filler used in coal mining.

consideration. A carbonate extender with otherwise equivalent properties but exhibiting a lower absorption than competing extenders is of special interest. Such an extender may permit higher loadings of the extender while still achieving a paint with equal or better properties at a lower manufactured cost.

Lower oil absorption can be achieved by modifying the particle size distribution of a carbonate extender in such a way as to achieve "optimum packing density" i.e. a particle size distribution with a minimum amount of void spaces.

Other factors of equal importance are: product availability, reliability of supply, constant uniform product quality, product and transportation cost. The deciding factor is always the cost effectiveness of the extender pigment.

Coarser sized carbonate extenders are commonly used in production of flat (low sheen) paint, while the finer carbonate extenders are used to produce semi-gloss or glossy paints.

The level of addition varies for flat or glossy paint and also for the type of resin used. In general up to 3 lbs. of carbonate extender per gallon is used in flat or semi-gloss paints. Up to 1 lb. per gallon is used in glossy paints.

The most common carbonate extenders used by the paint industry have the following particle sizes:

45 microns top size, Hegman 4–Grade II
20 microns top size, Hegman 5–Grade 1
12 microns top size, Hegman 6–Grade 1
8 microns top size, Hegman 7–Grade 1

Superfine calcium carbonates are now being used or evaluated as substitutes for calcined kaolin clay. Calcined kaolin is used in certain paints as a "spacer" for the prime pigment, titanium dioxide (TiO_2). The superfine carbonate fillers typically have a lower oil absorption than calcined kaolin clays, allowing higher loadings. These new type fillers, which also find applications in plastics and paper, have a top size of approximately 4 microns (.00016") and a 0.8 micron (.000032") average particle size and are available in natural or coated form; the latter types for use in plastics applications.

The technology for producing such fine products is not willingly shared by the producers. It is based on a "wet grinding" process, using grinding equipment developed in Europe and Japan.

Coarser carbonate extender paints are used in architectural type coatings, such as coating systems for concrete blocks. Such paints are commonly referred to as block sealers. Coarse grade carbonates are also used in textural paints to create a stucco type finish. These carbonate extenders are of a coarse granular type ranging from 10 mesh downward in size.

Plastics

The prime purpose of using mineral fillers in plastics is as a resin extender. Resin costs have escalated rapidly during the past decade because they are derived from petroleum. Thus mineral fillers have become more attractive as bulk fillers or reinforcing agents because they are substantially less expensive than the resin. The use of coating and coupling agents has created a new generation of fillers which impart a number of desirable properties to the plastic.

The following properties of minerals are important if the filler is also to act as a reinforcing agent. Calcium carbonate fillers, in their natural state, usually do not have reinforcing properties.

1. Good dispersion in the polymer system. This can be improved by coating the filler.
2. In general, oil or polymer absorption should be as low as possible, allowing high loading levels of filler, but there are some exceptions to this.
3. Fillers for most applications should have a low density to minimize the weight of the final product.
4. Fillers must not contain any free moisture.
5. A high degree of whiteness is usually preferred.

Fillers affect the properties of the products in which they are used, and their effect depends not only on the type of filler and the degree of loading but also on the particle shape and fineness of the filler (Kriens 1978). In general, untreated mineral fillers will have the following influence on the properties of the plastic:

1. The modulus of elasticity is decreased in all plastics.
2. Elongation is decreased, proportionally to the amount of filler addition.
3. The flexural modulus is increased.
4. The flexural strength is reduced by non-reinforcing fillers.
5. Compressive strength is decreased by some fillers such as barite, calcium carbonate and talc.

The ultimate objective of the plastic producer or compounder is not only to save on resin cost, but also to reduce overall production cost. This objective is well achieved when the filler can be used as a "bulk filler" as long as it does not have any adverse effect on equipment performance or cause excessive wear on it. However, in some cases the use of fillers may increase the compounding cost for the plastic, but the increased cost is offset by other benefits which the filler contributes.

Calcium carbonate is the highest volume filler used today by the plastics industry (McMurrer 1982). The major volume applications are in polyvinyl chloride and glass reinforced polyesters. Use of calcium carbonate in plastics has experienced rapid growth as a result of increased costs for oil from which plastic resins are derived. Calcium carbonates incorporated in plastic resins are found to be excellent resin extenders, that do not materially affect the physical properties of the manufactured product. In comparison to the cost of the plastic resins, calcium carbonate is a low cost, readily available resource.

Considerable research has indicated the advantages that can be gained from fillers treated with surface coatings, coupling agents, finer particle sizes and fillers with modified particle size distributions. Research on the use of mineral fillers in plastic continues at a fast pace and the current status can best be described as dynamic. Hence it is not surprising that the growth rate of the use of fillers in plastics has equalled or exceeded the growth of plastics production itself. This trend is expected to continue until the end of the century (Reynold and Roussopoulus 1978). The plastics industry itself is an industry that has experienced very high growth rates. Production of plastics in the United States in 1945 was approximately 360,000 tonnes; by 1973 it was 12.2 million tonnes (Clarke and Watson 1980).

The volume of all fillers consumed in plastics in the United States is expected to reach 14.5 million tonnes by the year 2000 (Reynolds and Roussopoulus 1978). The volume of all grades and types of calcium carbonate, including precipitated calcium carbonate, consumed in plastics in the United States in 1981 is estimated at 400,000 tonnes.

Current research and development is concentrating on achieving higher loading levels, finer grades, partial replacement of titanium dioxide and possible application of hybrid filler systems, such as combinations of calcium carbonate with aluminum tri-hydrate. Surface coatings enable higher loading levels, reduced melt viscosity, lower power requirements, improved rheological properties and better impact and aging properties (Koller 1980).

The major applications for calcium carbonate are in polyvinyl chloride and polyester (Crowe and Kummer 1978). Other thermoset applications are urethane, including reaction injection molding (R.I.M.), epoxies and alkaline phenolics. Other thermoplastic applications are in polypropylene and polyethylene.

Calcium stearate and stearic

Table 10 Summary of Applications for Calcium Carbonate Filler in Plastics

Polymer	**Filler Level phr***	**Particle Size microns**	**Remarks**
Flexible PVC	20-60	3	Compared with coarser grades, fine fillers cause less of a decrease in physical properties and provide better performance in thinner calendered films and coatings.
PVC plastisols and organisols	20-100	wide range	Coarse grades for carpet backings to ultra fine precipitated grades and coated chalk whiting for thixotropic viscosity control. Coarse particles lead to lower viscosity in plastisols.
Rigid PVC	1-5 40	2-3 1-3	Application in plastic for potable water pipe. Other pipe and conduit applications. Stearate-coated grades improve melt rheology and smoothness of extrusion; uncoated grades serve as antiplate-out agents.
PVC floor tile	80-400	small	Finest grind is about 12 microns; size distribution is wide; colour varies with feedstock.
Sheet moulding compound	200	3-6	Used in low viscosity one and two component resins. Moisture content must be kept below 0.1% for controlled thickening during maturing.
Bulk moulding compound	250	3-6	Loadings are usually 250 phr for BMC, 100-150 phr for premix preform, and mat–over 400 phr is possible. Size, distribution, and purity are selected to provide low-uniform-viscosity polyester.
Marine polyester	175-200	3-5	Meets standard requirements for this application of 0.15% maximum water absorption during a 24 hour immersion.
Polypropylene	43-67	1-3	For both polypropylene homopolymer and copolymers

*parts per hundred of resin
Reference: Crowe and Kummer, 1979.

acid are the most common coating agents used. Kenrich has published extensive data on the use of titanate coupling agents and benefits derived from these coupling agents (Monte and Sugarman 1978 and 1980).

Suppliers continue to search for new surface modifying agents for optimizing cost/performance benefits. There is concensus that the ideal surface treatment has not been found (McMurrer 1982).

The primary function of coupling agents is to produce a filler with improved bonding between the resin and the filler. The stronger this bond, the better the physical properties of the final product are likely to be. In many instances a coupling agent can change a filler or extender with no reinforcing properties to one with distinct reinforcing properties. However, coupling agents have not found extensive use in calcium carbonates; they are most effective on silicate minerals. Only one large calcium carbonate producer in the United States is marketing carbonate fillers treated with titanate coupling agents.

Some newly developed coupling agents are reported suitable for calcium carbonate fillers, resulting in enhanced physical properties of the end products (Anonymous 1982).

Coating fillers with coupling agents requires special equipment and processing technology. In the majority of cases the type of coupling agent and filler have to be tailored to the specific polymer in which the filler is to be used. For this reason the treatment is usually performed by the filler producer or by companies specializing in filler treatment on a custom basis. Because of the diversity of resins and fillers it is not practical for resin manufacturers to market filled resins containing coated or coupling agents.

Paper

The paper industry consumes large quantities of mineral fillers, particularly kaolin, for paper filling and paper coating. Other natural minerals used in paper are talc, bentonite and calcium carbonate. Synthetic fillers, such as aluminum hydrate, blanc fixe (precipitated barium sulfate), precipitated silica, titanium dioxide, silica gel and precipitated calcium carbonates are also used in paper filling and coating.

Next to kaolin calcium carbonate, natural or precipitated, is the most common mineral used in paper.

Precipitated calcium carbonate was preferentially used in paper making for many years. It was produced as a co-product of the Solvay process in the making of sodium carbonate, but the availability of high quality natural soda ash from Wyoming, and high energy and environmental costs have resulted in the gradual phasing out of Solvay process plants in North America. It can also be produced by the so-called soda-lime process, or by the carbonation of milk or lime.

The paper industry itself is a potential source of precipitated calcium carbonates. Two U.S. paper makers, Champion and Olin, reportedly produced 47,000 tons in 1977 (Kline 1978).

Current commercial producers of precipitated calcium carbonates are Pfizer and Mississippi Lime.

The shortage of precipitated calcium carbonate developed in the 1970's. Producers of ground calcium carbonate recognized a market opportunity and were quick to respond with finely ground natural calcium carbonates as a replacement. Precipitated calcium carbonate has a very fine particle size. As a result calcium carbonate filler producers needed to extend their fine grinding technology in order to comply with the requirements of the paper market. In 1977 only two United States based companies offered a paper grade calcium carbonate, but currently there are eight producers of paper grade calcium carbonates in the United States marketing products in bag, bulk or slurry form.

Specifications for paper grade calcium carbonates fall in the category of superfine products. The top size is usually 10 microns or less with most grades having a top size of 4 to 5 microns and an average particle size of 0.6 to 0.8 micron.

High brightness is an absolute necessity for calcium carbonates used in paper filling or coating. Low abrasion characteristics (as measured by the Valley abrasion method) are essential, to minimize wear of high speed paper coating equipment. Rheological properties (i.e. the viscosity of the filler dispersed in high solids slurries) are also important to the paper maker.

Precipitated calcium carbonates are of superior chemical purity and brightness, and natural calcium carbonates usually contain traces of silica. Because of its hardness silica is detrimentally abrasive to paper-making machines, so the paper industry is particularly wary of natural calcium carbonate fillers.

Paper Filling

Natural or precipitated calcium carbonates can only be used as a paper filler, not as a coater, in plants using the "basic sizing" process in the production of the paper sheet or in unsized paper, such as cigarette paper.

The basic sizing process is used by only a small segment of the paper industry in Canada and the United States. Most companies now use the acid sizing process in which calcium carbonate filler cannot be used because of its high reactivity in an acidic environment. As a result inert fillers such as kaolin and the more costly filler titanium dioxide must be used.

The basic or neutral sizing process, was expected to gain in popularity, but the paper industry has not converted to the basic sizing process at the rate that was originally anticipated despite the associated benefits of less costly fillers, reduced equipment corrosion, closed circuit "white water" operation which reduces pollution, and the energy required to heat process water. Nevertheless conversion to alkaline sizing is expected to continue at an accelerated rate.

The amount of carbonate filler used in paper is dependent on the type of paper produced and whether the paper is to be coated or uncoated. Several mineral fillers can be used, and the choice is usually based on technical considerations, paper type and quality, and cost of the fillers.

Typical filler levels in uncoated paper range from 5 to 15 percent. The filler level in coated papers is usually 3 to 9 percent.

Fillers are usually less costly than wood fibers, thereby reducing the cost of the paper. They also contribute to the properties of the paper. However, high filler levels generally reduce the paper's strength. But ground calcium carbonate, used as a filler in alkaline-sized paper, produces a stronger paper, allowing higher calcium carbonate loadings. This is particularly true for the superfine grades of calcium carbonate, and it should have a positive effect on the rate of utilization of calcium carbonate as a paper filler as the conversion to alkaline sizing proceeds.

Paper Coating

The paper industry is the largest consumer of mineral fillers. Coated paper consumes large volumes of water washed, delaminated and calcined kaolin. Other major minerals used in paper coating are precipitated and ground calcium carbonate.

Natural calcium carbonates used for paper coating are always the superfine grades with a top size of 4 microns and an average particle size of less than 1 micron. These grades are produced by a wet grinding process and are supplied to the paper industry in bulk, bag or as a predispersed slurry. The superfine ground calcium carbonates compete directly with precipitated calcium carbonates.

Ground calcium carbonates for paper coating must have high brightness, low abrasion and very fine particle size.

Precipitated or ground calcium carbonate contributes to the color (whiteness) of coated paper. It also improves the ink receptivity and smoothness of coated paper.

The paper coating accounts for 20 to 30 percent of the weight of coated paper. Kaolin is the prime mineral filler used in paper coating with calcium carbonate, alumina hydrate and titanium dioxide of secondary importance.

Traditionally only precipitated calcium carbonate was used in paper coating, but poor availability of the precipitated grades presented opportunities to producers of ground calcium carbonate. The challenge was to produce a ground product with a very fine particle size, high brightness and low abrasion. In 1977, the first of the superfine ground products were introduced by two suppliers, quickly followed by other major producers. Superfine, ground calcium carbonates are marketed at prices competitive with precipitated grades. As a result ground calcium carbonate is finding acceptance as a replacement for precipitated calcium carbonate in paper coating applications.

Prices

Natural ground, superfine calcium carbonates suitable for use in paper filling or paper coatings are designated as Grade 1. They include the superfine grades with average particle size of less than 1 micron and a top size of 5 microns, and the fine grades with an average particle size from 1 to 3 microns and a top size of 10 to 15 microns. In North America the superfine grades are only produced in the United States. In Europe calcium carbonates have a longer history of use in paper filling and coating and enjoy a larger market share than in North America.

The superfine products are sold at prices ranging from U.S. $128 per tonne in slurry form (based on dry weight) to U.S. $175 per tonne for dry products.

The fine grades are sold at prices ranging from U.S. $95 per tonne for grades with an average particle size of 3 microns to U.S. $145 per tonne for grades with an average particle size of 1 micron.

Putty, Caulks, Sealants

Putty, caulks and sealants are a group of related products with wide ranging industrial applications. They are used to seal joints, seams or fill cracks. Uses in the construction industry amount to 70 percent; the automotive and aircraft industry accounts for 20 to 25 percent.

Ground calcium carbonate is a widely used filler in these products. Its excellent availability, whiteness, low oil absorption and low cost make it the filler choice in these products.

Because of its low oil absorption, calcium carbonates can be used at high loading levels, while maintaining good flow and viscosities in the finished product.

Calcium carbonate provides bulk and reinforcing properties to putty, caulks and sealants. Most of these products are applied from gun type cartridges and must have good flow properties. Other minerals such as barite, kaolin, talc, bentonite, precipitated silicas and asbestos are used. The latter provide thixotropy to the products so they will not sag, particularly on vertical surfaces.

Filler loading is typically 40 to 50 percent but can be as high as 90 percent in putty where calcium carbonate is the filler most often used. The prime function of the filler is to provide bulk and reduce the overall cost of the product.

For most applications a good white colour is desirable. In some product applications, lower quality off-white calcium carbonates can be used. Filler selection, other than for performance, will be based on the cost competitiveness of the filler. On this basis, white fillers produced by local producers may have an economic advantage.

Specification

Calcium carbonate fillers used in putty, caulks and sealants cover a wide range of dry ground, air classified products. Particle sizes range from Grade I, with an average particle size of 2–3 microns to Grade III products with as much as 20 percent retained on a 200 mesh sieve.

Sealants and caulking compounds typically use the finer grade products while in putty the coarser grades are used In caulking compounds a blend of fine (Grade I) product with coarse (Grade III) product is sometimes used to achieve optimum properties.

Putty, caulks and sealants are the third highest volume market for calcium carbonate fillers after carpet backing and plastics.

Prices

Prices for calcium carbonate products used in putty, caulks and sealants range from U.S. $30 to $90 per tonne.

Rubber

Calcium carbonate fillers are used in soft rubber goods such as rubber floor covering, auto mats and other flexible rubber products. Kaolin is the primary filler used in this type of rubber with calcium carbonate the second most popular filler.

Calcium carbonate fillers are added to reduce product cost. It provides a good neutral base for coloring with pigments. Calcium carbonate has no reinforcing properties in rubber. However, it can be used at high loading levels without significantly affecting the softness or resilience of the product.

Calcium carbonate fillers are one of the primary fillers used in wire and cable coatings, automotive weather stripping and in some footwear applications.

Filler loading level is dependent on the required product characteristics. In low performance rubber products, filler content may be as high as 50 percent by weight. Lower filler levels are used in higher performance products. Other fillers may be added to the formulation to provide reinforcing properties.

Calcium carbonate products typically used in low performance rubber products are Grades II or III.

In wire and cable coatings calcium carbonate is used in conjunction with different types of kaolin. Grade I fillers, natural or surface coated with stearates, are used in this application.

Prices

The cost of Grades II and III calcium carbonate fillers used in rubber products ranges from U.S. $40 to $110 per tonne for the uncoated grade while the stearate coated # I grade is sold for U.S. $150 per tonne. The above prices are f.o.b. plant in 22.7 kg (50 lb) paper bags.

Vinyl Flooring and Vinyl Fabrics

Calcium carbonate is used extensively as a filler in vinyl flooring systems. Other mineral fillers used in vinyl flooring are talc, kaolin, wollastonite and asbestos. A combination of two or more fillers are usually used to achieve the desired properties of the flooring product. The use of asbestos in vinyl tile has decreased considerably in recent years.

Ground calcium carbonates of different fineness grades are used in vinyl flooring. They range from Grade II products with up to 0.5 percent retained on a 325 mesh sieve (44 microns) to Grade IV products with up to 20 percent retained on a 200 mesh sieve (74 micron). A coarse Grade IV granular product with a top size of 40 mesh (420 microns) and 90 percent or more retained on 200 mesh (74 microns) is the most common filler product used in vinyl tile.

Producers of vinyl tile select the fillers best suited to give the properties desired. A combination of a coarse Grade IV product with a fine Grade II product is sometimes used. Calcium carbonate fillers are used in combination with other mineral fillers.

Loading levels range from 20 to 30 percent for the Grade II fillers and as high as 70 to 80 percent for the coarse Grade IV and granular products.

The main criteria for vinyl tile fillers are high brightness, easy dispersability, low binder demand and low abrasion. Fillers improve the dimensional stability of vinyl floor tile; the stiffness of tile increases with filler loading.

In vinyl floor tile the coarse granular Grade IV products are used, while vinyl sheeting uses Grade II products. Vinyl fabrics for automotive upholstery requires Grade I or II products.

Prices

Prices for Grade II fillers used in vinyl tile cover the range U.S. $44 to $50 per tonne. Coarse Grade IV filler is sold at prices ranging from U.S. $24 to $33 per tonne. Grades I and II used in vinyl fabrics range from U.S. $44 to $110 per tonne. Granular, 40 by 200 mesh (420 x 74 microns), is priced at U.S. $40 to $50 per tonne.

All the above prices are for bulk carload shipments f.o.b. point of production.

Carpet Backing

Carpet backing is the largest volume application for calcium carbonate fillers. It is used to provide body and weight to the carpet backing, which is made from latex rubbers. High level loadings are possible in carpet backing. As much as 500 parts of filler for each hundred parts of latex can be used in some latex systems without affecting durability or the viscosity of the latex during processing.

Both high grade white and off-white grades of calcium carbonate fillers can be used in carpet backing, often in conjunction with aluminum hydrate. Aluminum hydrate is added to achieve fire retardancy and smoke suppression.

Medium (Grade II) and coarse ground (Grade III) products are used in carpet backing. These grades range from products with 99.5 percent passing a 325 mesh sieve (44 microns) to grades as coarse as products where up to 10 percent is retained on 200 mesh (74 microns). Grade selection is based on the type of latex system used and/or the type and quality of carpet with which the carpet backing is to be used.

Carpet backing is produced by either the carpet manufacturer or by special latex compounders.

Prices

Calcium carbonate fillers used in carpet backing are low cost products, easily produced in large volumes. They are less sophisticated products, the major requirement being low binder demand and a fair degree of brightness.

Products used in carpet backing are sold in the range of U.S. $20 to $50 per tonne.

Jointing Compounds

Ground calcium carbonate fillers are used in joint cements used to seal and finish joints in dry-wall wallboard panels. The fillers used are coarse ground Grade II and III products. Typical products are 90–99 percent passing 325 mesh (44 microns) and coarser 200 mesh products. Calcium carbonate content of the joint cements can be as high as 80 percent by weight.

White colour is important, but of greatest importance is the application characteristics of the joint cements. These products are applied with applicator knives, and joint cements must have good application characteristics, must not sag on vertical surfaces, and not crack on drying. The colour of the joint cement after drying and the sanding properties are also important considerations.

Slightly off-white products can be used. Blending white high quality grades with low cost off-white or slightly gray limestone fillers may still achieve the desired colour quality. Delivered cost is a prime consideration in selecting fillers for joint cements.

Prices

Carbonate fillers for joint cements are sold in bulk and bags. The f.o.b. plant price of bulk shipments range from U.S. $40 per tonne for high quality white fillers to less than U.S. $30 per tonne for the off-white filler grades.

Asphaltic Products

Limestone and dolomite fillers are used extensively in asphaltic roofing products such as shingles and rolled roofing. They are also used in asphaltic sealers for coating driveways, and in sound deadening types of automotive undercoating.

In Canada the maximum allowable filler loading of roofing shingles is 50 percent. Standards in the United States allow a 60 percent loading level.

The fillers used are coarse, Grade III and IV types. The main specifications are controlled particle size, good flow properties and high bulk density. Either dolomite or limestone fillers can be used.

Prices

Cost of the filler is most important, and therefore these types of fillers are usually purchased from local aggregate producers. Prices range from U.S. $15 to $25 per tonne in bulk f.o.b. producing plant.

Dolomite Fillers

Dolomite based fillers are used in a number of industrial applications, such as roofing asphalts, sound deadening undercoating, carpet backing aand caulking compounds. The products are typically produced as by-products of dolomite quarrying and crushing operations in the production of dolomitic lime used by the steel industry. Products are coarse Grade III fillers, usually off-white or cream coloured.

There is little or no North American production of finely ground high purity filler from white dolomitic marble. Although deposits of high purity dolomitic marble are known none have as yet been developed in competition with calcitic marble. The ready availability of high purity calcitic marble, traditional usage and lack of detailed performance characteristics appear to be the main reasons for the limited use of dolomitic fillers in North America.

By contrast, high quality dolomitic fillers are used extensively in Europe for paints, plastic and other applications where high whiteness, low oil absorption and low abrasiveness are required. Data appears to be lacking in respect to its use in paper filling and coating. There appear to be no technical reasons why dolomite is not being used in plastics and paint in North America.

In paint the possible chemical reaction of dolomite with sulphur dioxide, which in combination with water forms sulphurous acid, results in water soluble magnesium sulphate. This may lead to the formation of white streaks. Although calcium carbonate is a more reactive mineral than dolomite its reaction product with sulphurous acid is calcium sulphate, an insoluble salt.

The above is a general hypothesis that the authors have not been able to confirm from published data. The European experience suggests that there is no technical reason for not using fillers produced from dolomitic marbles.

There have been reports that indicate that magnesium carbonate fillers may cause yellowing of paper. However, it is not known if this is related to the use of dolomitic marble or for precipitated magnesium carbonate.

Obviously, more research on the use of high purity white dolomitic marble for fillers is warranted.

Producers

Canadian Producers

Steep Rock Calcite, a division of Steep Rock Resources Inc., produces a wide range of high quality calcium carbonate fillers at Perth, Ontario, from a white calcitic marble deposit located at Tatlock in Darling Township, 40 km north of the Perth plant. The quarry is located in a broad north-trending belt of white marble that dips 55° east. A zone of high-purity contains reserves in excess of 6 million tonnes grading about 53 percent calcium oxide, 1 percent magnesium oxide, low silica and a scarcity of other impurities. Natural brightness of the ground product is 95 to 97.

The ground marble products cover the spectrum from Grade I to IV and are used in a broad range of industrial applications. In 1983 the company expanded its plant capacity, mostly for increased production of Grades I and II. Processing is by dry grinding and air classification. Products are sold in bag and bulk.

In Western Canada, calcium carbonate fillers are produced by Imasco Canada Ltd., located in Creston, British Columbia. The company produces both carbonate and dolomite fillers in Grades II, III and IV.

In Montreal, Industrial Fillers Ltd. produces a range of off-white calcium carbonate fillers. Only coarse ground 200 and 325 mesh products are produced. Applications are in soft rubber goods, joint cements, carpet backing and putty. Annual capacity is in the order of 90,000 tonnes. There are several producers of low grade off-white calcitic fillers in southern Ontario. Domtar Chemicals' Lime Division in Beachville, and Beachville Lime Company in Ingersoll, produce industrial fillers as a by-product from limestone aggregate and glass grade limestones production.

Beachville Lime produces two filler grades: a 200 mesh (74 microns) product and 325 mesh (44 microns) product which are used in latex rubber cushions, caulking compounds, carpet backing, roofing shingles, rubber mouldings, weatherstripping, asphaltic sealers and automotive undercoatings. The fillers have good chemical purity but have a cream-white colour which prevents their use in applications where high brightness is critical.

Domtar Chemicals' Lime Division produces a 200 mesh (74 microns) product, used in carpet backing, automotive undercoating and asphaltic roofing products.

Steetley Minerals, a division of Steetley Industries Limited, Hamilton, produces dolomite fillers at their aggregate and pulverized stone plant in Dundas, Ontario. The filler products are produced from fines that result during production of glass grade dolomite, fertilizer diluants and agricultural dolomite. The fillers are marketed primarily for use in asphaltic roofing.

E.C. King of Owen Sound produces dolomite fillers in conjunction with glass grade dolomite. The fillers are used in asphaltic roofing and sealer applications.

United States Producers

Limestone and dolomite fillers are marketed by a number of producers in the United States. They can be grouped into three categories:

1. Companies marketing limestone or dolomite fillers produced as a co-product with aggregates and granular products used by the construction, steel, glass and agricultural industries. Filler products produced are often of good chemical composition but lack the necessary whiteness to allow their use in applications where high brightness is required. These types of industrial fillers are utilized in applications where low cost is the most important consideration and colour is not critical.

Within the study area there are some five hundred producers of limestone and dolomite, many of which market a filler product, usually Grades III or IV. Products are marketed to local or regional consumers for such uses as roofing material and other asphaltic products, carpet backing and caulking compounds.

2. The second category of filler producers are the companies with dedicated facilities for the production of fillers as a prime product, rather than as a co-product or by-product. Source materials are limestone or dolomite from which slightly off-white fillers can be produced.

The following companies are typical of this second category. They produce a limited range of filler products, usually in the Grade III or IV category.

Dixie Lime & Stone Company, a subsidiary of the Belgian company Carmeuse SA, produces fillers at Sumterville, Florida.

Southern Materials Corporation produces some fillers from a high purity cream-coloured calcitic limestone near Ocala in central Florida.

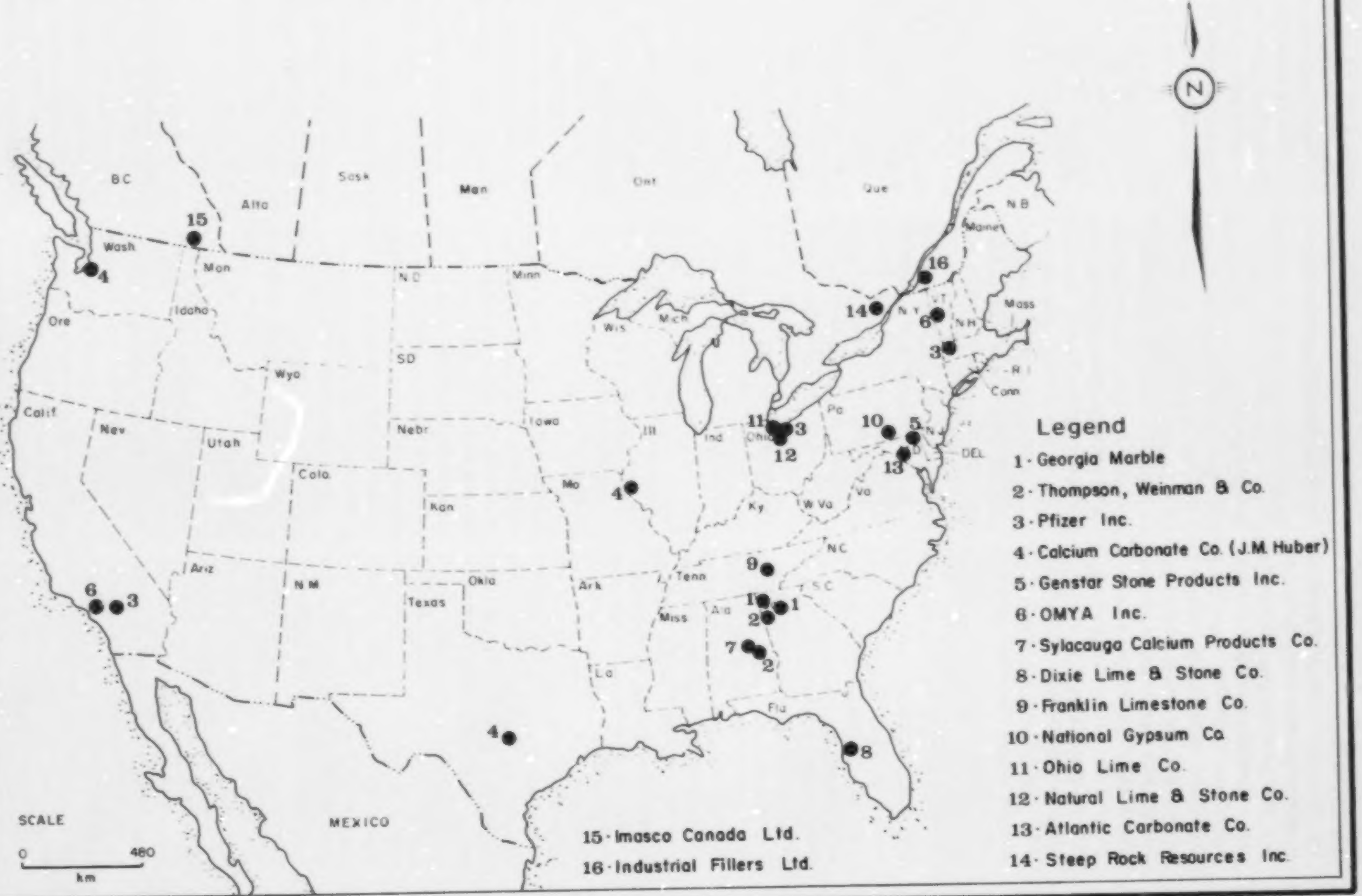
Franklin Limestone Company of Nashville, Tennessee, produces carbonate fillers at a plant located in Crab Orchard, Tennessee.

National Gypsum Company, York, Pennsylvania, produces carbonate fillers, most of which are for captive use.

Ohio Lime Company, a division of Steetley Industries Ltd., Ham-

Figure 9

PRINCIPAL PRODUCERS OF FILLER-GRADE CALCITIC AND DOLOMITIC CARBONATE



Legend

1 · Georgia Marble
2 · Thompson, Weinman & Co.
3 · Pfizer Inc.
4 · Calcium Carbonate Co. (J.M. Huber)
5 · Genstar Stone Products Inc.
6 · OMYA Inc.
7 · Sylacauga Calcium Products Co.
8 · Dixie Lime & Stone Co.
9 · Franklin Limestone Co.
10 · National Gypsum Co.
11 · Ohio Lime Co.
12 · Natural Lime & Stone Co.
13 · Atlantic Carbonate Co.
14 · Steep Rock Resources Inc.
15 · Imasco Canada Ltd.
16 · Industrial Fillers Ltd.

ilton, Ontario, produces dolomite fillers at their plant in Woodville, Ohio.

The National Lime & Stone Company produces dolomitic fillers at their plant in Carey, Ohio.

Pfizer Inc., Minerals, Pigments and Metals Division produces dolomitic fillers at their plant in Gibsonburg, Ohio.

The Calcium Carbonate Company, a division of J.M. Huber Corporation produces a full range of slightly off-white fillers at their plant in Quincy, Illinois. This company also offers a "chemically brightened" calcium carbonate filler of high quality for use in paper.

3. The third category of carbonate filler producers are those grinding very white marble. There are eight major producers, but several operate more than one grinding plant. All produce a full range of calcium carbonate fillers, including the superfine grades developed in recent years.

The major producers are:

Atlantic Carbonate Company is a joint venture of Genstar Stone Products and Anglo-American Clays, a subsidiary of the English China Clay Company of St. Austell, Cornwall, England. It produces primarily superfine grades of calcium carbonate used by the paper industry. Production is from the plant at Texas, Maryland.

Calcium Carbonate Company, a subsidiary of J.M. Huber Corporation, operates calcium carbonate plants located at Marble Falls, Texas, its new plant at Seattle, Washington, and the Quincy, Illinois, plant discussed in the previous category.

Genstar Stone Products Inc., formerly Flintcote Stone Products, produces a wide range of calcium carbonate filler products, mostly the Grade I and II types, at their plant at Texas, Maryland.

Georgia Marble Company, a division of Jim Walter Corporation, produces a wide range of fillers at Gantt's Quarry, Alabama, and Tate, Georgia. Georgia Marble also has a grinding plant at Dalton, Georgia.

Omya Inc. is a fairly recent entrant into the North American calcium carbonate filler scene. Its parent company, Pluess-Staufer AG of Switzerland, has for many years been a leading producer of calcium carbonate in Western Europe. Omya Inc. acquired the Vermont Marble Company in Proctor, Vermont. It has constructed new calcium carbonate grinding plants at Proctor, Vermont, and La Habra, California. Omya is a major supplier to the paper industry.

Pfizer Inc., Minerals Pigments & Metals Division produces high brightness calcium carbonate fillers at Adams, Massachusetts, and Lucerne Valley, California. As discussed in the preceding section, Pfizer also produces dolomitic fillers at Gibsonburg, Ohio.

Sylacauga Calcium Products is a division of the Moretti-Harrah Marble Company Inc. and produces calcium carbonate fillers from a quarry and plant located in Sylacauga, Alabama.

Thompson, Weinman & Company, a subsidiary of Cyprus Industrial Minerals Co. owned by Standard Oil of Indiana, has quarries and plants located at Gantt's Quarry, Alabama, and Cartersville, Georgia. Thompson, Weinman is also a partner with Omya Inc. in the White Pigment Company at Florence and New Haven, Vermont, and York, Pennsylvania.

Consumption

Carbonate minerals are among the least expensive and most readily available of the filler minerals. There are few substitutes that are economically competitive. Deposits suitable for fillers are reasonably widespread in the study area. In some cases low grade fillers are made from dust products resulting from the processing of limestone and dolomite for construction and other uses.

Paper

Currently there are an estimated 125,000 tons of finely ground calcium carbonate used as filling and coating pigments in the paper industry, partly for reduced gloss and improved ink receptivity. Also a change from the acidic paper process favoring kaolin to the alkaline process favoring calcium carbonate is receiving widespread industry attention (McComb and Williams, 1981; Paiste, 1981). The alkaline process produces a more permanent and durable paper. This interest has caused several European producers of calcium carbonate to establish production facilities in the United States and this has resulted in a competitive response from domestic ground and precipitated calcium carbonate producers. As well, diversification into calcium carbonate production by some of the domestic kaolin producers has been initiated.

Paint

Carbonates used as fillers in the paint industry for their whiteness, brightness, and low oil absorption, are readily available in a variety of particle sizes at attractive prices. At the present time there are approximately 250,000 tonnes of limestone used as filler in paint. Dolomite is not normally used because the magnesium carbonate may dissolve under the influence of sulfur dioxide to form soluble magnesium salts which cause rapid deterioration of exterior surface coatings.

Plastics and Rubber

Carbonate fillers are the most common mineral raw material used in plastic and rubber products. This is principally because of the large tonnage of carbonate filler used in rug backing and hard surface floor coverings such as vinyl tile. It is relatively inexpensive and widely avail-

Table 11 Estimated Carbonate Filler Market, 1980-1985

	Total Canada and United States	Study Area
	Tonnes Annually	
Putty, caulks, sealants	480,000	300,000
Carpet backing	500,000	50,000
Plastics	400,000	300,000
Paint	250,000	110,000
Paper	125,000	80,000
Rubber	100,000	75,000
Adhesives	25,000	15,000
	1,880,000	930,000

able in many particle sizes and grades.

Others

Carbonate fillers are widely used in putties, caulks, sealants, and tape compounds.

Changes in paper processing from acid to alkaline systems will result in an immense increase in the amount of calcium carbonate used in paper. This possibility has been anticipated by several major producers of calcium carbonate in the United States and they have developed plants to service these markets when they develop.

Consumption of carbonate fillers is estimated in Table 11. Statistics for filler grade carbonate minerals are not separately reported from other gross uses of limestone and dolomite, either in Canada or the United States.

Competitive Materials

Calcium carbonate fillers compete with other fillers in a number of applications. This competition can be for technical or economic reasons. Calcium carbonate is a universal filler of low cost and excellent availability. It has been used for many years in some applications and has an almost unassailable position in such applications as paint, carpet backing, vinyl flooring and other polyvinyl chloride products.

Paint

In paints, calcium carbonate fillers compete with nepheline syenite, silica and talc. Each of these minerals imparts different desirable properties to a paint. Combinations of calcium carbonate with other fillers is typical in interior and exterior paint formulations.

Carpet Backing

In carpet backing its low cost, easy dispersion, lack of abrasiveness and low binder demand have made calcium carbonate the filler of choice. In this application, calcium carbonate competes with ground feldspar, a product it has almost completely replaced.

Vinyl Flooring-Sheeting

A similar condition prevails in the vinyl flooring industry, particularly vinyl tile where calcium carbonate is used at high loading levels. Low cost, good white color, low abrasion and binder demand are the main reasons for its use. Nepheline syenite is a potential competitor in this market.

Putty, Caulks and Sealants

The same desirable properties and low cost are responsible for its use in putty, caulks and sealants. It competes with talc and air floated or water washed kaolin in caulking compounds. Calcium carbonate is the most common mineral filler used in putty.

Plastics

Ground calcium carbonate fillers have more significant advantages in plastics. As a bulk filler, with no reinforcing properties, calcium carbonate is a choice filler in polyvinyl chloride, polyester and phenolics where low cost, good colour, low oil absorption and other desirable properties have made it a popular resin extender. Calcium carbonate and most other mineral fillers received a considerable boost in demand during the early seventies due to the dramatic increase in the cost of petroleum based feedstocks necessary for resin production; increased loading levels for fillers helped offset these costs. Competition comes from such minerals as talc, mica, water washed and calcined kaolin, feldspar, nepheline syenite and wollastonite.

The use of mineral fillers in plastics is still growing and the development of special and coated products will continue to advance their utilization. Calcium carbonate producers will continue to share in this expanding market.

Paper

In paper, it is not a question of competition as much as the use of new technology that will herald more extensive use of calcium carbonate in paper filling. Here, calcium carbonate is the new product, competing with its counterpart precipitated calcium carbonate as well as with kaolin for a share of the filler market as conversion to the alkaline sizing process proceeds.

In paper coating the superfine grades of calcium carbonate compete with precipitated calcium carbonate and with coating grades of kaolin as a paper coating pigment.

Rubber

Calcium carbonate and air floated, soft kaolin compete in filler applications for low performance soft rubber goods. Low cost, white colour, ease of dispersion and low abrasion are the desired properties.

Joint Cements

Calcium carbonate fillers compete with air floated kaolin, mica and talc in joint cements. Calcium carbonate or kaolin act as the bulk filler, while mica and talc are added to improve troweling, reinforcing and anti-cracking properties.

General

Calcium carbonate is a nearly ideal filler with widespread commercial use. Its relatively low cost, high brightness, low oil absorption, softness and high chemical purity are the properties desired in most applications. Its excellent availability in many grades from multiple sources is an important consideration. Geographically, it is available throughout the United States. In Canada, high quality calcium carbonate fillers are produced in Ontario and British Columbia.

Trends

Many of the industrial applications in which calcium carbonate fillers are used are in mature industries such as paint, putty, caulk, sealants, jointing compounds and rubber. Growth in filler consumption is dependent on the development of new technology or new uses and on development of specialty filler products with unique properties.

The plastics and paper industries are the two major fields of application where considerable growth in the consumption of calcium carbonate fillers is expected. The new superfine grades of calcium carbonate are likely to see increased use in plastics as performance of these new grades become better known. Further development of surface coatings and functional coupling agents are also expected to increase the use of calcium carbonate fillers in plastics. High loading levels may also be achieved with "particle size modified" filler grades.

The ready availability of the superfine ground calcium carbonates as a substitute for precipitated calcium carbonate will be a factor that could influence the conversion by the paper industries to the "basic sizing" process. There are technical and economic factors that suggest that this conversion will take place at an accelerated rate.

6 Kaolin

Summary

Kaolin comes closer to being an ideal filler than any other natural mineral: it is white, has good covering power, is soft and non-abrasive, is chemically inert over a relatively wide pH range, has low conductivity of heat and electricity, and is low in cost. It has many applications, and many grades are specifically designed for uses in paper, paint, rubber, plastics and ceramics.

The United States produces about 40 percent or world supply from extensive sedimentary deposits in Georgia and South Carolina. Second in importance are residual deposits in Cornwall in Southwest England. Both are generally worked by open pit methods: the Georgia deposits by large draglines; the Cornwall deposits by high pressure water monitors. In both cases beneficiation is usually by wet methods. Large existing reserves have recently been greatly enhanced by the successful application of high-intensity wet magnetic separators to remove iron-bearing and other stained and off-colour particles.

Paper is the principal market for kaolin, where it is universally used for both filling and coating purposes. Kaolin is not used in newsprint or pulp, the principal products of Canada's paper industry, but it may comprise as much as 30 percent by weight of high quality papers. Kaolin fills the interstices between the wood fibres, contributing bulk and stiffness to the paper. When further applied as a coating it gives smoothness, whiteness, weight and ink receptivity to the paper.

Canada produces no kaolin of paper quality, but extensive deposits in the Moose River Basin of northeastern Ontario may have such potential. Widespread government drilling programs in recent years is focussing increased interest in these Cretaceous sedimentary materials.

Kaolin is under some threat from calcium carbonate for filling paper because it is less expensive, has lower absorption and greater whiteness. However, it can only be used where the paper-making process uses alkaline sizing, and while there is a definite shift in the industry to an alkaline process most existing plants still use an acid medium.

Estimated annual market for kaolin within the study area is 2,555,000 tonnes, of which paper accounts for 2,200,000, plastics and rubber 200,000, paint 90,000 adhesives 40,000, inks 15,000, and others 10,000.

Geology

Commercial kaolin is largely composed of the mineral kaolinite, which has the chemical formula $Al_2O_3.2SiO_2.2H_2O$ and a theoretical composition of:

SiO_2–46.54%
Al_2O_3–39.50%
H_2O–13.96%

Kaolinite is the most common member of the kaolin group of minerals: Kaolinite, nacrite, dickite and halloysite. While these minerals have slightly different crystal structures they all have essentially the same composition.

As an economic commodity the term "kaolin" has been defined by Patterson and Murray (1975, p.546) as follows.

> Kaolin is a clay consisting of substantially pure kaolinite, or related clay minerals, that is naturally or can be beneficiated to be white or nearly white, will fire white or nearly white, and is amenable to beneficiation by known methods to make it suitable for use in whiteware, paper, rubber, paint, and similar uses. The term is applied without direct relation to purity of deposits. Many very large kaolin deposits are essentially pure, and they require little beneficiation during preparation for market. Most are slightly off-color and require bleaching, and others contain as little as 10% clay that must be washed and concentrated to recover marketable kaolin.

Commercial kaolin deposits generally contain certain mineral impurities: The most important North American sedimentary deposits in Georgia are generally 85 to 95 percent kaolinite, the rest quartz, mica, ilmenite and other titanium minerals, and zircon. The residual deposits of Cornwall, England, and Spruce Pine, North Carolina, are only 10 to 40 percent kaolinite, the rest being quartz, muscovite and feldspar.

Kaolinite is a secondary mineral, formed from feldspathic minerals by chemical weathering or hydrothermal alteration. Most Kaolin occurrences throughout the world have formed during the last 100 million years, particularly during the Cretaceous Period when world climate was generally warmer and more humid than now. Geographically, deposits favour tropical or subtropical areas where abundant rainfall, warm climate and organic acids from decaying vegetation have caused the decomposition of feldspars and the removal of alkalies in solution. If the alkalies are not substantially removed, illite or mica will tend to form instead of kaolinite in the presence of potash, and montmorillonite in the presence of magnesia. Lime also inhibits the formation of kaolinite; neither will it form in a marine environment.

There are two types of kaolin deposits, residual and sedimentary. Residual deposits are the result of chemical weathering of feldspathic rocks, wherein the feldspars are more or less decomposed to kaolinite which remains in a matrix of more resistant minerals, usually angular quartz, mica and potash feldspar. Sedimentary deposits may be formed by the subsequent transport of the kaolinite in streams to a fresh water depositional basin, or more generally by the subsequent kaolinization of a previously depositied feldspathic sand.

Residual deposits are irregularly shaped, and grade downwards through partly decomposed rock to the unweathered parent rock. They may also contain blocks and fragments of partially altered parent rock.

Sedimentary kaolin deposits are in the shape of tabular lenses and discontinuous beds that may be as much as 20m thick and more than 1km long. Kaolin in the ground is normally soft and plastic if moisture is present. If dry, it is usually friable.

Kaolin deposits formed by hydrothermal alteration are described by Patterson and Murray (1975 p.553) as follows.

> Such deposits are ordinarily in irregularly elongated pods or pipelike bodies aligned along joints, faults, or other permeable zones that allowed movement of warm or hot aqueous solutions. Some deposits of this type also occur in altered tuffs and are bedded. As with the residual type, the age of hydrothermal kaolin formation is not necessarily related to the age of the host rock. Most hydrothermal clay deposits are probably no older than Tertiary, though some occur in rocks that are much older. Insofar as the authors are aware, deposits in the Little Antelope Valley, California (Cleveland, 1957), contain the only hydrothermal kaolin now mined in the United States. It is used for refractory clay. However, kaolin formed by this process occurs at many places in the western states, and deposits were formerly mined on a small scale in several mining districts.

Producers and Occurrences

The United States dominates world production of kaolin, contributing about 40 percent of the total, largely from mines in Georgia. Eastern bloc countries contribute about 25 percent of the world supply. The United Kingdom accounts for about 16 percent from its Cornwall and Devon sources. Increasing production from Brazil is the most significant new feature among world producers (Watson 1982, p.17). Canada produces no kaolin, but extensive deposits in northern Ontario have attracted exploration interest for more than 60 years.

Canadian Occurrences

Prairie Provinces

The Cretaceous Whitemud Formation of southern Saskatchewan and Alberta includes thick beds of kaolinitic sand. The kaolinite content locally is as much as 50 percent, but is off-white and does not respond to bleaching.

A kaolinite-quartz sand deposit near Arborg in Manitoba, 150 km north of Winnipeg, is less than 100 m wide but can be traced for several kilometres. The best material consists of interlayered beds or lenses of sand and hard sandy clay. However, the clay layers are generally less than 3 m thick and the content of pale yellow to buff kaolinite is about 25 percent.

Quebec

In Quebec, a hydrothermally altered feldspathic quartzite at St. Remi d'Amherst was the source of some kaolin and silica sand production during the 1930's. Alteration of feldspar to kaolinite was accomplished in a deep zone of intense fracturing which gave access to hot aqueous solutions. Other small kaolin occurrences at Thirty-one Mile Lake in Blake Township, and in Arundel Township, Argenteuil County, have also been explored.

Nova Scotia

A thick sequence of interbedded and variously coloured plastic clays, quartz sands and lignite of Cretaceous age overlie Carboniferous rocks of the Musquodoboit Valley and Shubenacadie Basin of Central Nova Scotia. The clays are kaolinitic and are generally refractory but are only used for pottery and brick-making. Silica sand is also produced, but significant kaolin reserves have not been reported (Fowler and Stea 1984).

Ontario

Moose River Kaolin

Ontario has extensive deposits of kaolin that show promise of commercial quality. They lie beneath the muskeg and glacial overburden of the Moose River Basin, 800 km north of Toronto.

The Moose River Basin occupies the southern part of the James Bay Lowland, a flat featureless muskeg plain on the Arctic watershed that slopes northward imperceptibly into James Bay. Exploration in the Basin is difficult because of the poor of road access, the muskeg terrain, the scarcity of outcrop, the lack of topographic features, the generally inconclusive geophysical response, and the difficulty of obtaining satisfactory drillhole samples of the unconsolidated sedimentary materials.

The kaolin is dispersed in a saturated quartz sand deposit lying beneath a thick sequence of glacial overburden, 20 m to more than 100 m thick, topped by muskeg of 2 m to 4 m thickness. The technical problems of mining by open pit methods at such depths and under such wet conditions, not to mention the problems of maintaining a critical control on quality, are worsened by the long season of below-freezing temperatures. However, there is reason to believe that mining might be accomplished by pumping the clay-sand slurry to surface through cased wells.

The area of principal interest extends for 80 km marginal to the east-west Precambrian escarpment that forms the southern limit of the basin. Northward from the escarpment the deposits are known from sporadic drilling to extend for 40 km (Figure 10). The southern edge of the basin is accessible by road from Fraserdale and Kapuskasing. The eastern limit of the kaolin area is 15 km west of Coral rapids on the Ontario Northland Railway. Access to the Western part of the Basin is restricted to lumber roads north from Hearst, from which final access must be by winter road.

The Moose River Basin contains Quaternary and Mesozoic sediments which overlie Paleozoic rocks that form the bedrock throughout much of the James and Hudson Bay Lowlands. A detailed account of the geology is given by Telford and Verma et al (1982). It is believed that the kaolin and sand sequences are the weathered products of feldspathic rocks of the Precambrian escarpment that forms the south rim of the Basin, and that kaolinization took place largely after redeposition of a feldspathic sand in a shallow fresh water environment.

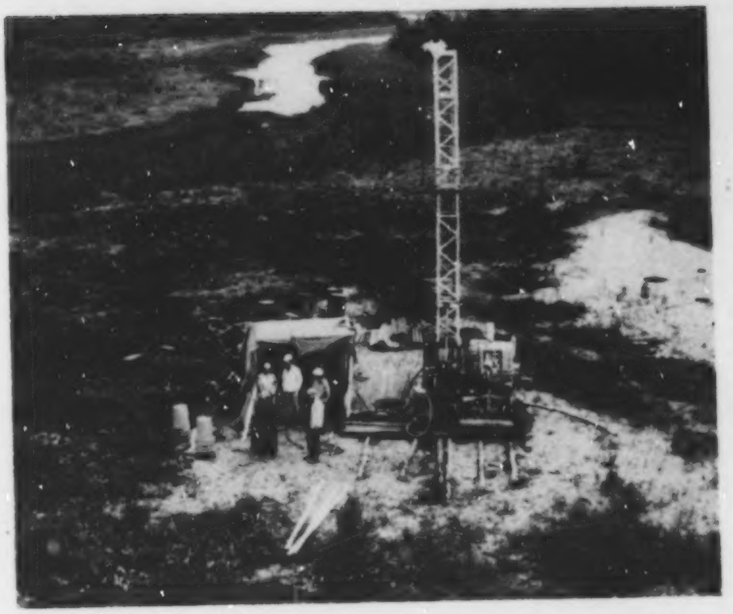


Photo 7 Drilling on typical muskeg terrain in the Moose River Basin, 1978.

A Precambrian ridge known as the Grand Rapids Arch appears to have formed a barrier to the deposition further north of the younger light-coloured Mesozoic sediments that contain the most attractive kaolin. Northeast of the arch, in the Onakawana area, the Mesozoic sediments are characterized by lignite and grey to black fireclays. Dark-coloured sediments are also present southwest of the arch, but they are overlain by thick beds of white kaolinitic quartz sand and light-coloured clay lenses. The dark and light-

Table 12 Chemical Analysis of Crude, Unprocessed – 325 Mesh Kaolin–Silica Mixtures
Moose River Basin

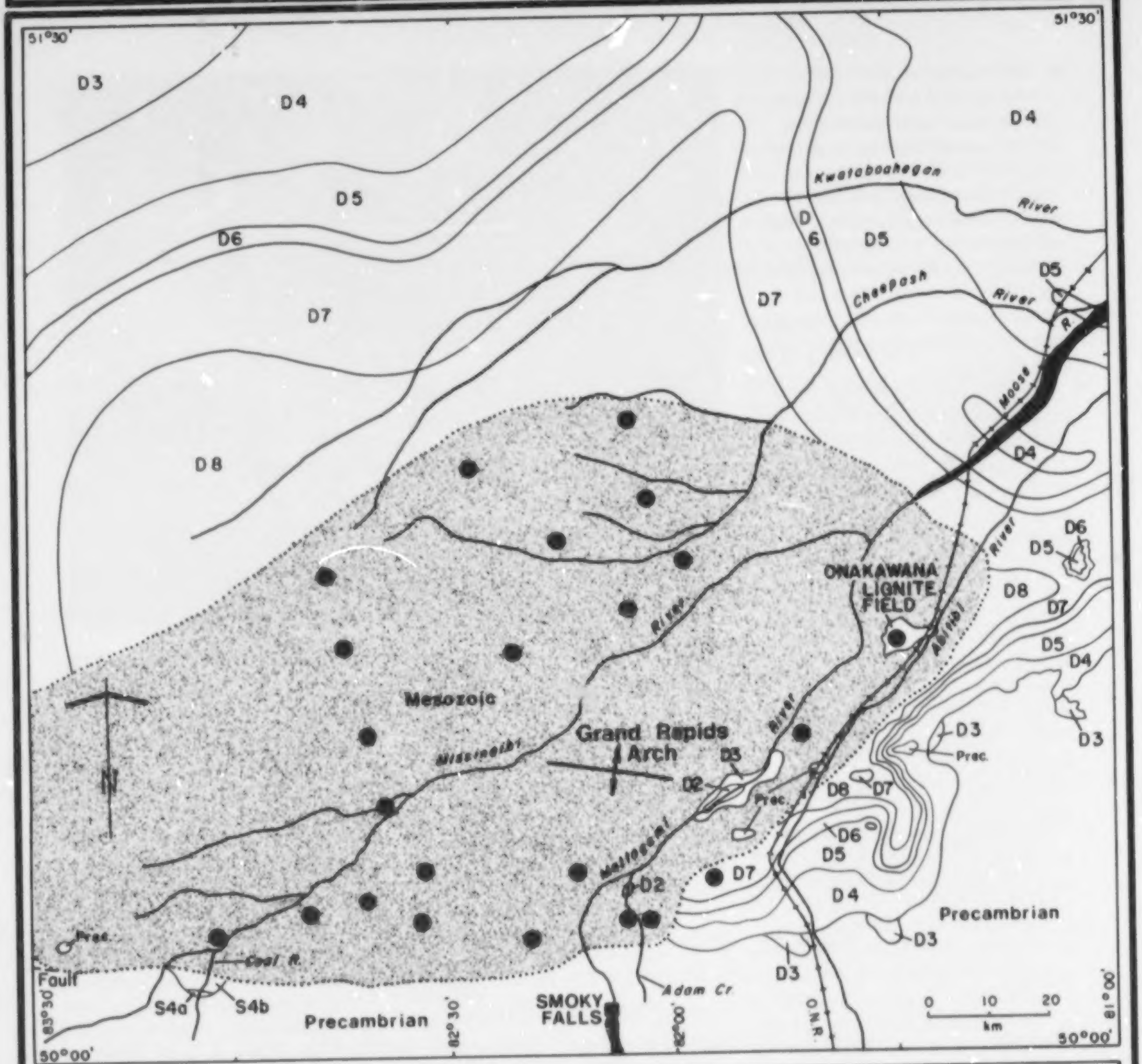
Sample	SiO_2	AL_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	MnO	TiO_2	P_2O_5	L.O.I.	SUM
SDT-1-3	64.4	24.8	0.30	0.08	0.00	0.12	0.59	0.00	0.30	0.03	9.15	99.9
SDT-1-4	63.3	26.3	0.11	0.02	0.00	0.10	0.37	0.00	0.25	0.03	9.54	100.1
SDT-1-6	73.6	18.2	0.09	0.01	0.00	0.10	0.37	0.00	0.35	0.04	6.93	99.8
SDT-1-7	52.7	32.0	0.14	0.07	0.02	0.23	0.81	0.00	0.86	0.04	12.5	99.4
SDT-1-8	52.5	33.4	0.12	0.06	0.01	0.24	0.56	0.00	0.44	0.04	12.4	99.8
SDT-1-9	54.2	32.2	0.13	0.06	0.02	0.23	0.55	0.00	0.42	0.04	12.1	100.0
SDT-1-10	57.5	29.1	0.16	0.09	0.00	0.30	0.84	0.00	0.62	0.04	11.0	99.8
SDT-1-11	52.1	32.5	0.12	0.09	0.02	0.30	1.05	0.00	1.18	0.03	12.2	99.8
SDT-1-13	68.6	20.5	0.16	0.05	0.01	0.18	1.15	0.01	1.03	0.04	8.08	99.9
SDT-1-14	56.6	29.4	0.15	0.12	0.04	0.34	0.95	0.00	1.37	0.05	11.0	100.1
SDT-1-15	56.1	28.7	0.17	0.17	0.02	0.45	1.16	0.00	1.39	0.05	11.3	99.6
SDT-1-16	52.8	32.5	0.12	0.08	0.03	0.34	0.90	0.00	0.88	0.05	12.2	99.8
SDT-1-17	57.5	29.1	0.10	0.06	0.02	0.61	0.84	0.00	0.75	0.04	10.8	99.9
SDT-1-18	57.0	30.1	0.11	0.07	0.04	1.07	0.69	0.00	0.36	0.04	10.5	100.1
NBS-97A	43.7	38.9	0.10	0.16	0.04	0.50	0.47	0.00	1.90	0.36	13.5	100.0
CONTROL	45.9	39.0	0.01	0.07	0.21	0.21	0.70	0.00	0.51	0.10	13.7	100.4

The control sample is a commercial quality coating clay.

Source: Selco, Inc.

GEOLOGY OF THE MOOSE RIVER BASIN

Fig. 10



Legend

Mesozoic

▨ Mattagami Fm. (Lower Cretaceous)
Mistuskwia Beds (Middle Jurassic)

Upper Devonian

D8 ..... Long Rapids Fm.
D7 ..... Williams Island Fm.

Middle Devonian

D6 ..... Murray Island Fm.
D5 ..... Moose River Fm.
D4 ..... Kwataboahegan Fm.

Lower Devonian

D3 ..... Stooping River Fm.
D2 ..... Sextant Fm.

Upper Silurian

D1 ..... Kenogami River Fm.

Precambrian

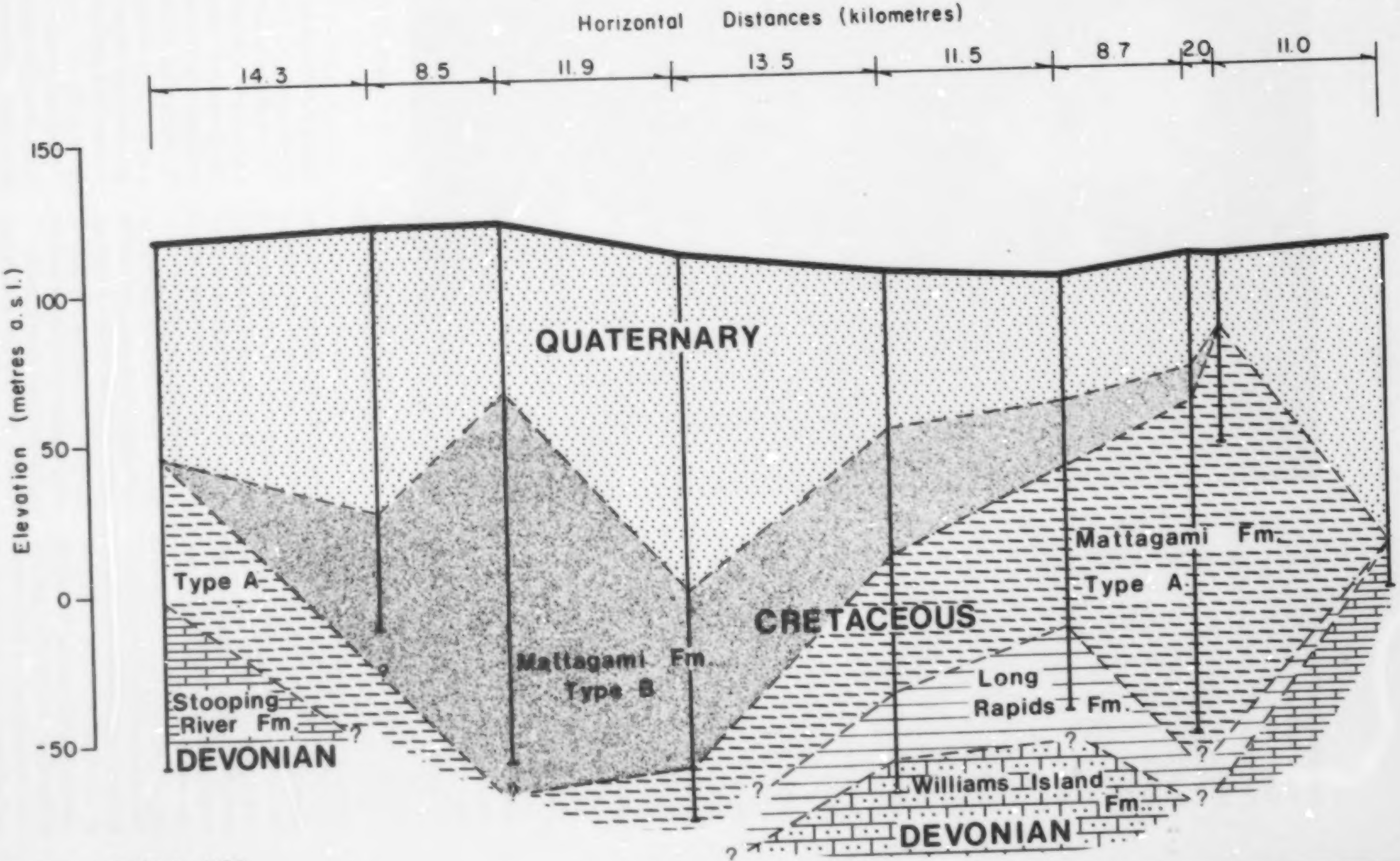
Undifferentiated

● Deep Borehole

(Modified from Telford & Verma, 1982)

Figure 11

EAST - WEST SECTION THROUGH MOOSE RIVER BASIN



Source : Guillet, 1979

coloured sequences are known respectively as the Type A and Type B units of the Mattagami Formation of Lower Cretaceous age.

Kaolin of possible commercial significance occurs as a white matrix between the quartz grains in the thick beds of quartz sand that comprise much of the Type B unit (Table 12). Horizontal lenticular beds of white and brightly-coloured plastic clay are also common. They consist almost entirely of kaolinite, and are generally highly refractory. Whether or not the whitest and purest lenses could furnish a commercial kaolin product, rather than simply a ball clay or fireclay product, has not been tested.

The entire sequence is water-saturated, and much of the fine white kaolin is mobilized in suspension throughout the sand beds, giving rise to kaolin-rich and kaolin-poor horizons. Kaolin-rich horizons may contain as much as 20 percent or more of kaolinite.

A maximum thickness of 127 m has been recorded (Guillet 1979, p.36) for the light-coloured Type B unit in a drillhole in the south-central part of the Basin. Kaolin-bearing sand horizons vary up to 20 m in uninterrupted thickness, but normally average 5 m to 10 m. Interbedded clay lenses are generally thinner.

While there has been some deep exploration drilling by private interests most field studies have been directed towards the few Cretaceous outcrops in deeply cut river channels. However, much of our present knowledge of these deposits has resulted from several deep drilling programs by the Ontario Government in recent years. Drill mobilization and servicing by helicopter during the summer months has proved more cost effective than the construction of winter access roads for winter drilling programs. Optimum sample recovery was obtained by using a combination of triple-tube coring equipment in clays and tills, and reverse circulation techniques in sands and silts. However, reverse circulation does not readily yield an uncontaminated kaolin sample.

Photo 8 Slurry of kaolin and quartz sand recovered by the reverse circulation drilling technique.

Analytical testing has been largely restricted to routine physical and chemical analyses. Bulk sampling and pilot scale testing to determine commercial suitability is lacking. It is still uncertain whether a kaolin product suitable for the all-important paper coating market can be made, although several independent private studies are believed to have been encouraging.

As to the lenticular clay beds interlayered with the kaolinitic sands, more data is available. Analyses of a random selection of clay samples obtained during a recent government drilling program show alumina values as high as 38.7 percent (Guillet 1979, p.46).

In summary, there is sufficient evidence of favourable quality to encourage further evaluation of the kaolin potential of these deposits. The Cretaceous sediments are widespread, extensive, and sufficiently variable to encourage the probability of high quality horizons containing large reserves.

Copper Mine Point
Several steeply-dipping beds of a soft reddish felsite, partly altered to kaolinite, were explored by drilling in 1963. They occur close to Highway 17 near Copper Mine Point, 90 km north of Sault Ste. Marie. The felsite beds have been hydrothermally altered, and contain about 35 percent kaolinite which, however, is pink in colour due to finely-divided hematite.

United States Producers

Kaolin is produced by about thirty companies in the United States, mostly from extensive deposits in Georgia and South Carolina, but also from Alabama, California, Florida, North Carolina and Texas (Table 13). High quality paper clays are almost exclusively produced from Georgia deposits. Other producing states serve mainly ceramic, refractory and filler uses other than paper.

Georgia–South Carolina

Kaolin deposits in the Georgia-South Carolina belt occur along the base of the Piedmont Plateau over a length of about 200 km and a width to seaward of 50 km. The principal producing areas are in Central Georgia, between Macon and Augusta, and in South Carolina near Aiken (Fig. 12). Kaolin has been produced from Georgia since 1741.

In Cretaceous time the southeast edge of the Piedmont Plateau was believed to be similar to the present coastline, with abundant offshore sand bars and swampy muddy lagoons and estuaries. Runoff from the crystalline rocks of the Piedmont region deposited feldspathic sands as deltaic sediments largely above the level of marine influence. After kaolinization, a complex winnowing process appears to have separated the kaolin and redeposited it in lenticular beds surrounded by, and interfingered with, micaceous quartz sands.

Kesler (1963, p.7-8) describes the deposits as follows:

> The kaolin deposits are generally lenticular.... they range from a few feet to perhaps a mile, but uniform quality is rarely found throughout a lens. Vertical thickness ranges from inches to about 50 feet, and many of the mined deposits have averaged about 20 feet. Contacts with enclosing sands are mostly gradational, but a few are sharp.

Georgia kaolin deposits are generally 85 to 95 percent kaolinite; the remainder is mainly quartz with minor muscovite, biotite, smectite, ilmenite, anatase, rutile, leucoxene, goethite, and traces of zircon, tourmaline, kyanite, and graphite (Patterson and Murray 1975, p. 552).

There is still much uncertainty to account for the unique quality of some of the Georgia deposits. According to Patterson and Murray (1975, p.555):

> Areas of disagreement center about explanations of how such very large deposits of fine-grained white clay could have formed in environments in which some sediments being deposited consisted of sand containing much more iron than does the clay. Furthermore an adequate explanation of origin of the deposits must account for the following facts: (1) some deposits of kaolin are finer grained than others; (2) some contain abundant accordionlike booklets and some do not; (3) gibbsite is present in some deposits and not in others; (4) lignitic layers or layers rich in organic matter are present in some deposits: and (5) smectite is present in some deposits in variable quantities.

Ultimate resources are very large, and only the most attractive deposits are presently being worked. Off-colour deposits of higher iron content and deposits beneath excessive overburden await future development.

Alabama

The main Georgia-South Carolina kaolin belt can be traced southwest from Macon to Andersonville, Georgia, thence west to Eufaula, Alabama. In the Andersonville and Eufaula areas gibbsitic bauxite occurs in thin tabular lenses within thicker beds of kaolin. The bauxite lenses range up to 5 m thick and 200 m long within kaolin beds of about 10 m thickness. These deposits are of Eocene age, generally younger than the kaolins of the main belt to the north, at least some of which are Cretaceous, but obviously derived from them by more recent geological processes. These areas are worked by a number of companies for high-alumina refractories and ceramics.

California

A sedimentary kaolin-quartz sand deposit is worked near Ione for the production of kaolin. Both raw and calcined kaolin is produced for refractories, and some finely ground kaolin is produced for paint and other filler markets and ceramics.

Florida

Edgar Plastic Kaolin Company has worked a Miocene deposit of kaolinitic sand and gravel at Edgar in northcentral Florida for many years. The deposit varies to 16m in thickness and contains about 15 percent of recoverable kaolin. The kaolin is used in ceramics, while substantial amounts of silica sand are produced for glass, foundry and other industrial uses.

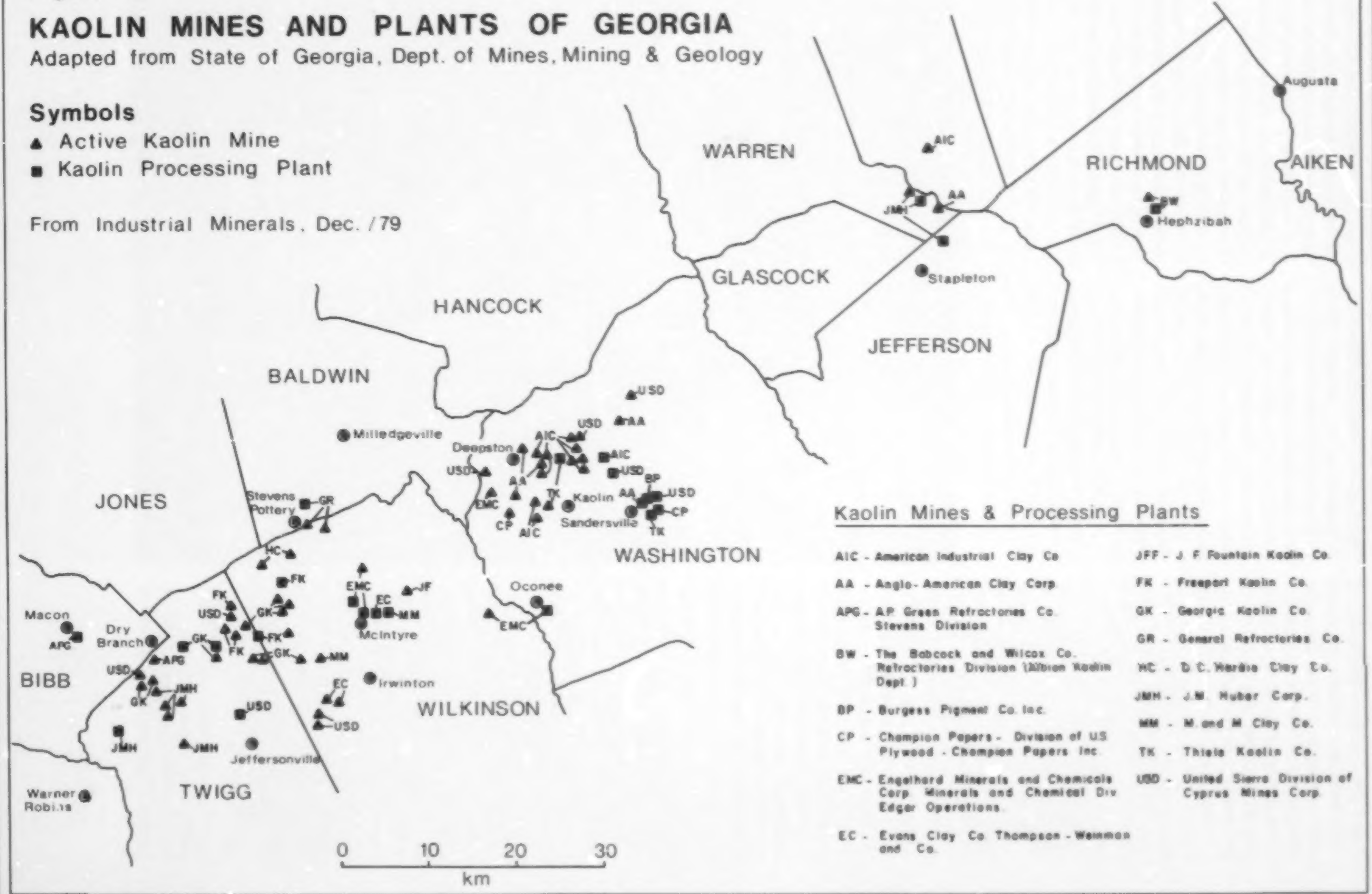
Texas

Texas Industrial Minerals works a kaolinitic sand deposit near Kosse for both silica sand and kaolin. The deposit is of Eocene age and contains 40-70 percent quartz. The sand is of glass-grade quality, and the kaolin is beneficiated and calcined for filler and ceramic uses.

Figure 12

KAOLIN MINES AND PLANTS OF GEORGIA

Adapted from State of Georgia, Dept. of Mines, Mining & Geology



Symbols

▲ Active Kaolin Mine

■ Kaolin Processing Plant

From Industrial Minerals, Dec. /79

Kaolin Mines & Processing Plants

AIC - American Industrial Clay Co

AA - Anglo-American Clay Corp

APG - A.P. Green Refractories Co. Stevens Division

BW - The Babcock and Wilcox Co. Refractories Division (Albion Kaolin Dept.)

BP - Burgess Pigment Co. Inc.

CP - Champion Papers - Division of U.S. Plywood - Champion Papers Inc.

EMC - Engelhard Minerals and Chemicals Corp. Minerals and Chemical Div. Edgar Operations.

EC - Evans Clay Co. Thompson - Weinman and Co.

JFF - J. F. Fountain Kaolin Co.

FK - Freeport Kaolin Co.

GK - Georgia Kaolin Co.

GR - General Refractories Co.

HC - D. C. Hardie Clay Co.

JMH - J.M. Huber Corp.

MM - M. and M. Clay Co.

TK - Thiele Kaolin Co.

USD - United Sierra Division of Cyprus Mines Corp.

Table 13 Kaolin Producers of United States

Company	**Location**	**Capacity ('000 tons)**	**Remarks**
American Cyanamid Co.	Andersonville, Ga		Bauxite/kaolin operation for firebricks, alum, and bleaching agent for paper.
Anglo American Clays	Sandersville, Ga	350	A member of the ECC Group–mostly coating clays.
Babcox & Wilcox Co.	Hephzibah, Ga	200	Mostly for refractories, but some for ceramics and glass fibre.
Buffalo China Clay Co.	Sandersville, Ga	50	Subsidiary of American Industrial Clays and Champion Papers Inc.
Burgess Pigment	Sandersville, Ga		Mostly calcined and surface treated clays for paint, rubber and plastics.
Cyprus Industrial Minerals	Sandersville, Ga Aiken, SC	240 60	Mostly for putty, caulks, sealants and adhesives.
C-E Minerals	Andersonville Ga	600	A bauxitic/kaolonitic clay used mostly for refractories.
Didier-Taylor	Eufaula, Alabama	100	Bauxitic/kaolinitic clay for refractories.
Dixie Clay Co.	Bath, SC	150	Air-floated clays mainly for rubber and plastics. A subsidiary of R.T. Vanderbilt.
Texas Industrial Minerals	Kosse, Texas		Calcined kaolin for paint. Subsidiary of Ottawa Silica Co.
Edgar Plastic Kaolin	Edgar, Florida	35	Owned by Pacific Tin Consolidated. Lump and pulverised kaolin for floor tiles, sanitaryware, and electrical porcelain.
Engelhard Minerals & Chemicals	Sandersville, Ga Irwinton, Ga McIntyre, Ga Gardner, Ga	1,150	Waterwashed clays, for paper, paint and adhesives.
Evans Clay Co.	Irwinton, Ga	120	Clay used in rubber, paint, and insecticide industries.
Eufaula Minerals	Eufaula, Alabama	300	A subsidiary of C-E Minerals. A kaolin/bauxite product for refractories.
Freeport Kaolin Co.	Sandersville, Ga Gordon, Ga	600	Around 350,000 tpa to paper; the rest to rubber, paint, adhesives plastics.
Fountain Kaolin Co.	Irwinton, Ga		
General Refractories	Stevens Pottery, Ga		Clay for refractories.
Georgia Kaolin Co. American Ind. Clay Corp.	Dry Branch, Ga Sandersville, Ga Wrens, Ga	1,600	Both companies are part of Combustion Engineering; Georgia Kaolin operates the Dry Branch and Wrens plants, and AIC the Sandersville plant, both being served by a number of clay pits.
A.P. Green Refractories	Eufaula, Alabama	60	Bauxite/kaolin clay for refractories.
Harbison Walker Refract.	Eufaula, Alabama	300	Bauxite/kaolin clay for refractories.
Harris Mining	Spruce Pine, NC	15	Mica/kaolin/sand operation.

Table 13 Kaolin Producers of United States (continued)

J.M. Huber Corp.	Wrens, Ga Huber, Ga Langley, SC Graniteville, SC Edisto, SC	1,300	The Georgia operations produce kaolin for paper, rubber, plastics, paint, and adhesives. At the South Carolina facilities air-floated and waterwashed products are processed for the rubber, fibreglass, conditioning, and agricultural markets.
Medusa Portland Cement Co.	Perry City, Ga		Material for additive to cement production.
M&M Clays Inc.	Irwinton, Ga	80	Clays for the rubber industry.
National Kaolin Products	Aiken, SC	100	Part of the W.R. Grace Group. Sales mostly for rubber.
Nord Kaolin Co.	Jeffersonville, Ga	295	Virtually all for paper.
North American Refract.	Ione, Calif.	200	Formerly Interpace Corp., now owned by Allied Corp. providing calcined (150,000 tpa) and airfloated (50,000 tpa) grades for refractory aggregates and fillers.
Southeastern Clay Co.	Aiken, SC	50	
Thiele Kaolin	Sandersville, Ga	400	The bulk of production serves the paper industry (coating and filler).
	Wrens, Ga	250	
Thomas Alabama Kaolin	Marion County, Alabama		Bauxite/kaolin clay mainly for refractories.

Source: Industrial Minerals, May 1982, p.31, with modification.

United Kingdom

The United Kingdom is the largest exporter of kaolin in the world, and second only to Georgia in world production of paper-coating grades. The deposits are residual, having formed by hydrothermal alteration of Permian granites which are widely exposed in Cornwall and Devon (Figure 13). The St. Austell Granite is the main source; kaolin occurs in funnel-shaped zones which narrow downwards but may persist to depths of more than 200 m. According to Patterson and Murray (1975 p.557):

> Hot acidic solutions are thought to have migrated upward, guided by structural weaknesses such as faults and joints, and then to have been trapped under a roof of relatively impermeable rock. The hot solutions attacked the granite, altering the feldspar and mica to kaolinite. Quartz, tourmaline, and mica are the principal impurities.

Some parts of the St. Austell Granite are only partially altered and consist of a mixture of feldspar, quartz, kaolin, mica, fluorite and other minor accessory minerals, the whole known as "china stone". At one time it was used extensively in making pottery, but increasingly less so today.

The main commercial kaolin pits are mostly worked by high pressure water jets, the resulting clay slurry collected in sumps and pumped away for further processing. Kaolinite content of commercial deposits ranges from 10 to 40 percent. Commercial production commenced in 1768.

Brazil

Sedimentary kaolin deposits along the Jari River, a tributary of the Amazon, have been developed in recent years, and now rank third in world importance in paper-coating grades. The deposits are thick and extensive, and very young in age (Pliocene, less then 7 million years).

The Caulim do Amazonia operation is now producing 200,000 tonnes per annum of paper-coating grades, plus other kaolin products. English China Clays do Brasil has recently initiated production; it plans to reach 59,000 tonnes per annum within two years, largely for the South American paper industry. A third company, Caulim do Para, has delayed its development plans as a result of the withdrawal of support by J.M. Huber Corporation (Watson 1982, p.17).

Mining Methods

In United States, kaolin is mined by conventional open pit techniques. In the United Kingdom, mining is more often done hydraulically.

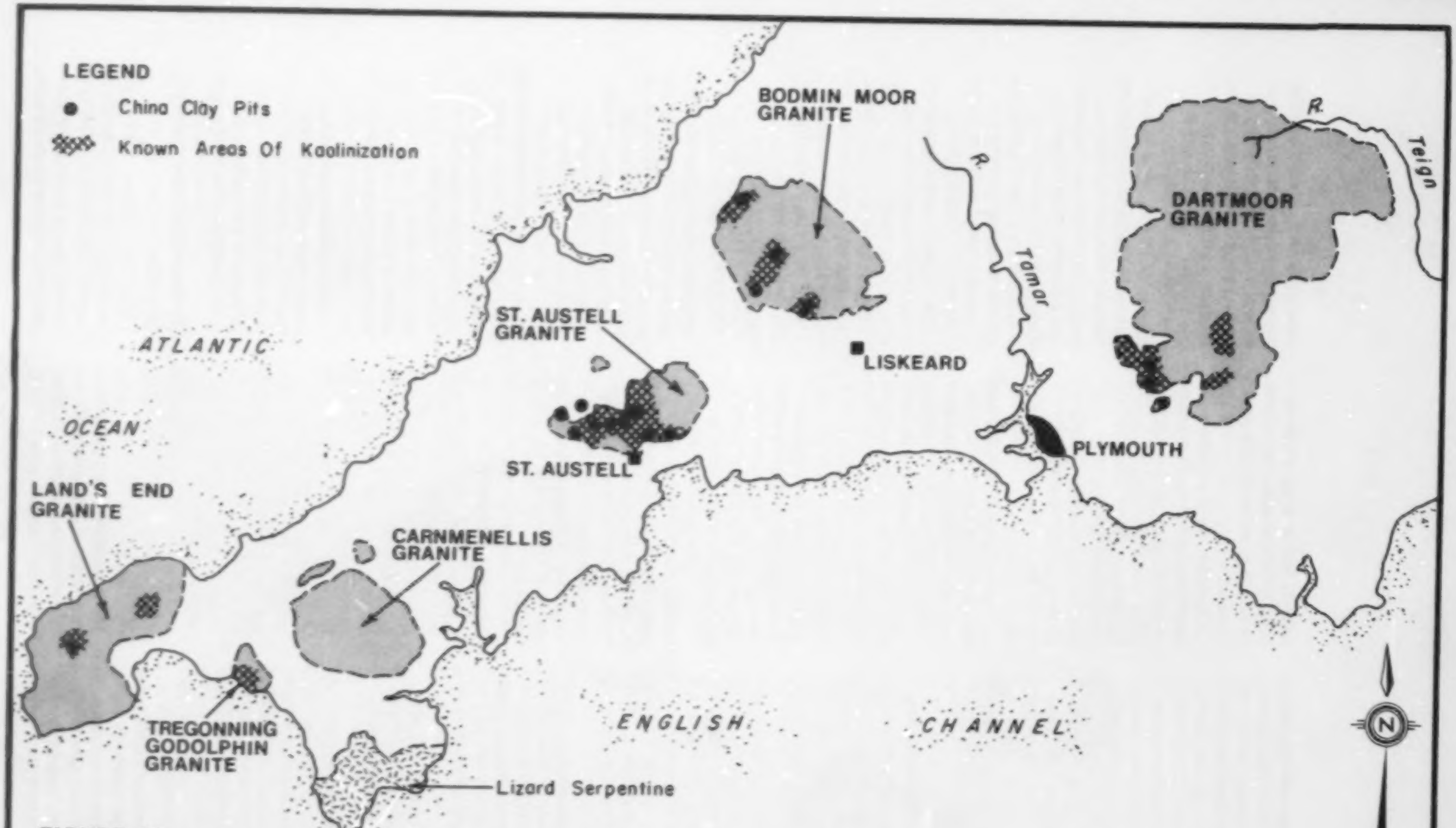


FIGURE 13

DISTRIBUTION OF KAOLINIZATION IN SOUTHWEST ENGLAND

(MODIFIED FROM WOODLAND AND HIGHLEY 1975, p.5)

Techniques for mining and exploration for kaolin in the Georgia-South Carolina sedimentary belt are well documented (Dotson 1977; Patterson and Murray 1975). The kaolin belt is broad and extensive, but the best deposits have already been developed or acquired. Usually only kaolin lenses of good colour, and containing at least 85 percent kaolinite, are worked, but more sandy and off-colour varieties also exist. Thickness of overburden is a major consideration; new deposits can only be located by drilling.

Exploration Techniques

In the Georgia-South Carolina kaolin areas, prospecting for kaolin is based on geological interpretation; geophysical and geochemical techniques have proved helpful.

Drilling is initiated on a grid pattern at a spacing of one hole every 5 or 6 hectares. Favourable results will encourage further drilling at 120 m centres, followed by 60 m centres. Pre-production drilling is often at 30 m centres to facilitate pit planning and quality control.

Drilling is advanced by reverse circulation techniques until the kaolin bed is reached, whence a 3 m core barrel is used for sample recovery. In most cases holes are limited to depths of 60 m.

Core samples are scraped to remove any contaminant, and cut into 60 cm composites for testing.

Useable beds average 6 m in thickness. Tolerable overburden ratios are presently about 7 to 1.

Samples are tested for brightness, bleachability, viscosity, percent grit content and particle size distribution.

Open Pit Mining

In the Georgia-South Carolina area, favourable deposits are worked by open pit methods.

Stripping of overburden is usually accomplished by self-propelled scrapers aided in some cases by large draglines. Topsoil is separately stockpiled for subsequent reclamation of the land.

Once the clay is uncovered it is drilled on 15 m centres using either the coring method or reverse circulation with air to remove the cuttings. Samples are composited for 30 cm intervals and tested as before for detailed mining control. Blending of crude clays of varying quality is often necessary

The clay is usually excavated by small draglines and fed into blungers where it is suspended in water with the aid of a dispersing agent. Pugmills are sometimes used to precondition the clay for the blungers.

The clay slurry is pumped to central degritting stations where coarse sand and mica is removed by gravity settling and/or wet cyclones, followed by screening. The product of this preliminary beneficiation is stored separately in tank farms until testing determines the blending necessary for feed to the main processing plant.

The slurry is pumped to the main processing plant through pipelines of 15 to 30 cm diameter, over distances of 10 to 32 km or more.

Hydraulic Mining

The Devon and Cornwall deposits in the United Kingdom are usually worked by hydraulic mining. These are residual deposits which may contain 10 to 40 percent kaolinite, the rest unaltered, or partially altered, minerals and rock fragments. By nature, therefore, they are not as pure as the Georgia deposits, and a simple concentrating technique is essential to avoid handling excessive amounts of waste rock. Hydraulicing accomplishes this, as described by Patterson and Murray (1975, p.557):

> In most places, the clay can be mined using high-pressure water jets, but sometimes blasting or ripping is required to loosen the rocks. Selective mining is very important because of variability in the various deposits. Much blending is done to produce a uniform product. As the rock face is washed, the slurry containing the kaolin in suspension flows to the lowest point in the pit. The slurry is then pumped into spiral classifiers which remove the coarse material. After this initial classification, the slurry is pumped to the surface of the pit where hydrocyclones remove finer sand and mica particles. The slurry is then thickened in large diameter tanks. A series of refining tanks is used to remove the heavier coarser particles. After primary classification, the slurry is fed to centrifuges to separate the coating kaolin from the filler grade. The kaolin is dewatered by filter presses and is dried.

Processing Technology

The geological history of a kaolin deposit can materially affect the processing technology required to beneficiate it. Hence a thorough knowledge of its mineral composition is imperative.

Kaolins are arbitrarily classified into "hard" and "soft" clays, designations which reflect their properties rather than their physical form. Hard clays, when used in rubber, produce a high modulus, high tensile and good abrasion resistance. Soft clays produce a lower modulus, lower tensile and abrasion resistance in rubber.

Commercial quality paper grade clays and soft rubber grade clays are produced from both residual and sedimentary deposits. Hard rubber grade clays are of sedimentary origin.

Preliminary Laboratory Studies

Laboratory studies should be undertaken to determine the important characteristics of the raw kaolin. These studies are to establish a number of important criteria that will allow a preliminary assessment of the potential for producing high quality kaolin products such as for paper coating.

Test samples of the crude kaolin should be treated as follows:

1. Removal of particles coarser than 200 mesh.
2. Determination of brightness.
3. Determination of mineralogical composition, and identification of the types of clay minerals present.
4. Removal of "grit" coarser than 325 mesh.
5. Dispersion of clay with suitable dispersants.
6. Fractionation of sample to determine yields of paper coating and paper filling grades. Paper coating grades should be 80 to 90 percent finer than 2 microns while paper filling grades are from 60 to 70 percent finer than 2 microns.
7. Determination of response to chemical bleaching and high intensity magnetic separation.
8. Filtration and drying of the obtained product.
9. Determination of brightness of prepared products.
10. Determination of viscosity of a dispersed clay-water slurry at 70% solids. Dispersant is added to obtain the minimum viscosity at this solids level. This minimum viscosity must be compared to the viscosity of a known quality paper coating kaolin.
11. Determination of the abrasiveness of the prepared products using the Valley abrasion tester, and comparing the abrasiveness with commercial quality paper grade kaolins.
12. Determination of chemical composition of the crude clay, the composition after grit removal and after fractionation and bleaching.

In all cases the test results must be compared to the quality characteristics of commercially used paper coating and filler clays. Other tests must be conducted on the degritted minus 325 mesh crude kaolin for its reinforcing properties in rubber.

General Process Considerations

The process selection depends on the nature of the deposit and the intended applications of the products to be produced. Ceramic and most rubber clays can be produced by dry processing of the dried crude kaolin after removal of coarse impurities. Some paper filling grades can also be produced by the dry process. The dry process consists of drying the clay, followed by pulverizing and air classification, a process largely restricted to sedimentary kaolin deposits containing a high percentage of kaolin.

Wet processing must be used to produce paper coating and most paper filler grades of kaolin. Wet processing is generally necessary for kaolin production from residual deposits containing high amounts of abrasive components.

Primary Processing

The primary processing of kaolin is essentially a process in which the kaolin is separated from abrasive minerals like quartz and minerals such as mica and refractory minerals. This process is simpler in the case of secondary deposits which have undergone natural classification during transportation from their original sources. Most of the resistant minerals have been removed during transportation, leaving relatively small amounts of abrasive minerals. By contrast, the separation of kaolin from primary deposits is more difficult because of the generally high content of abrasive minerals, mica and other accessory minerals that have survived the alteration process.

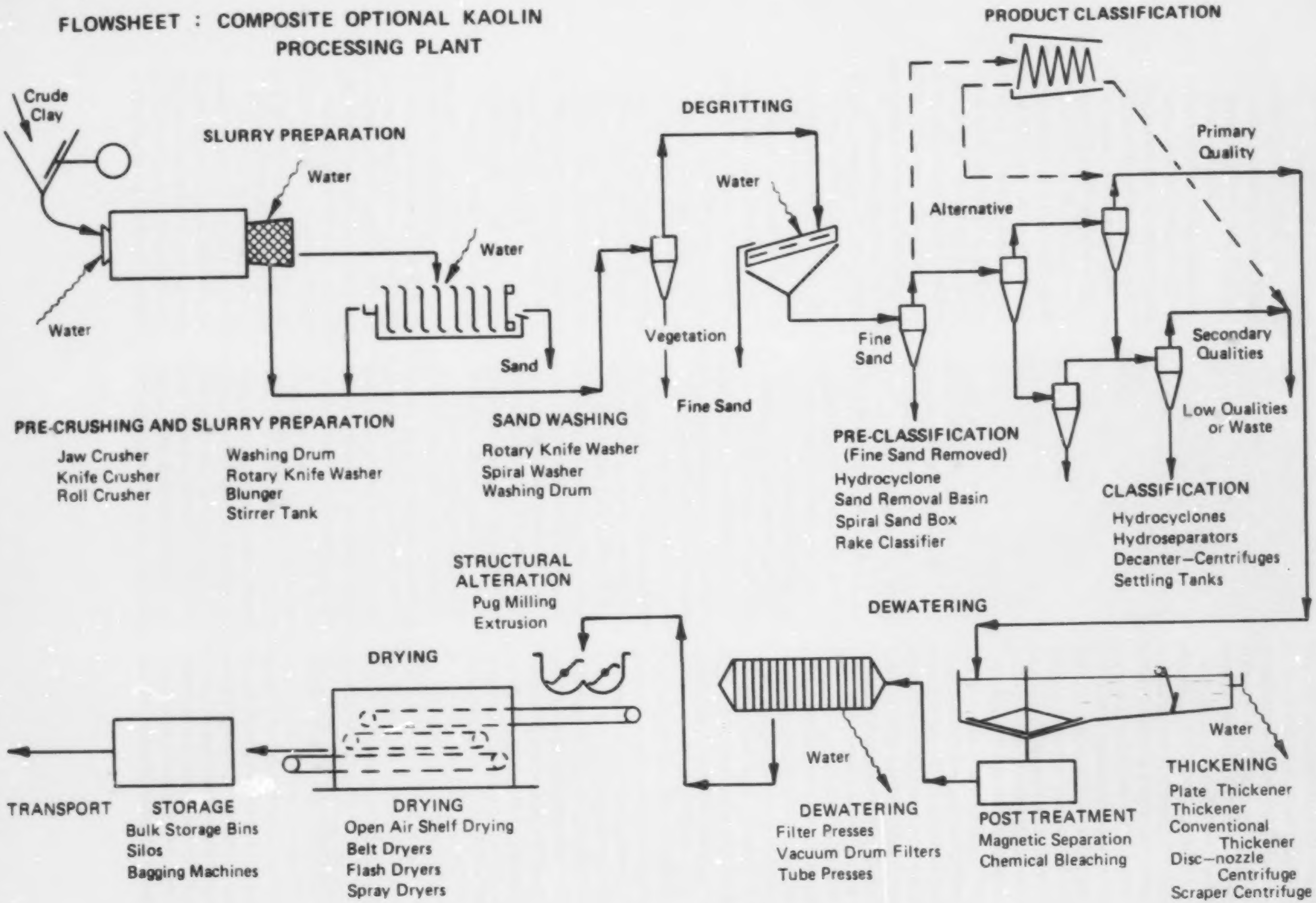
Kaolin deposits vary considerably in such important properties as particle size, colour, and type and amount of other minerals. To achieve the desired quality of the end products, selective mining and blending from different locations in the deposit is often necessary.

Primary Wet Processing

Regardless of geological origin, colour and particle size, the initial separation process is similar. The crude kaolin is slurried (blunged) in a drum with water, and a suitable dispersant is added to assist in the dispersion and deflocculation of the kaolin. The amount and type of dispersant used is determined experimentally and is based on achieving a minimum solution viscosity. The resulting slurry is discharged from the drum over a trommel screen which is an integral part of the washing drum. Coarse sand, roots, sticks and other contaminants, together with any undispersed clay lumps are retained on the screen and subsequently pumped or otherwise transferred to a spiral or rotary knife washer to which water is added. The coarse sand settles out and is conveyed by the action of the spiral or knives to the high side of the washer, while the kaolin slurry overflows from the low side of the washer. The coarse sand is pumped to the waste disposal system.

The kaolin slurry that passed through the trommel screen of the primary washer combines with the overflow from the secondary washer. At this point the slurry consists of kaolin, fine sand and any remaining contaminants such as leaves, roots and other finely divided organic debris. It is pumped to static or vibrating screens equipped with water washers, to remove the remaining organic material. The underflow from the screen, free of these contaminants, is then pumped to hydrocyclones, primary centrifuges or settling tanks to remove fine sand (Figure 14).

FLOWSHEET : COMPOSITE OPTIONAL KAOLIN PROCESSING PLANT



SOURCE : H.TRAWINSKI, HANDBOOK OF CERAMICS, 1979

FIGURE 14

During the primary separation process the solution densities must be carefully controlled in order to achieve effective separation. The density at which the separation is made depends on the amount and nature of the undesirable minerals and other contaminants, and on the amount of kaolin. Solution densities may range from 5 to 40 percent solids.

Secondary Wet Processing

Most kaolin requires additional benefication to produce products of commercial quality. This can take many forms, dependent on the quality characteristics of the primary slurry. The kaolin processor may face a number of problems of varying complexity, the most common problems and their possible solutions being:

Problem

1. The clay slurry contains fine abrasive minerals.
2. Poor brightness of clay slurry.
3. Coarse particle size, causing low yields of paper coating grade kaolin.
4. Poor solution rheology, i.e. high viscosity at 70% solids.
5. Poor response to standard bleaching or magnetic separation methods.
6. Organic contaminants, graphite, etc.

Possible Solutions

1. Further separation using hydrocyclones, centrifuges of settling tanks.
2. Wet high intensity magnetic separation, chemical bleaching, froth flotation, or combinations of these methods.
3. Delamination of coarse fraction by attrition milling, pug milling or extrusion.
4. Delamination as above unless caused by bleaching procedures.
5. Develop alternative bleaching procedures
6. Mix clay-water slurry with a water soluble, non-ionizable organic liquid, followed by separation of the clay-water phase from the organic phase.

Removal of Abrasive Components

It is normal to find that the primary clay slurry, while free of grit, still contains unacceptable amounts of "free silica" or other abrasive components.

Fractionation of the crude kaolin by sedimentation or centrifuge can establish if the abrasive components are retained in the coarse fraction or evenly distributed throughout. This can be done in the laboratory, using the standard sedimentation technique based on the settling rates of particles according to Stokes Law. In this test the clay is dispersed, using a suitable dispersant such as sodium tripoly phosphate or Calgon. The slurry density is fifty grams of kaolin in 1000 cc. of water and 0.5 grams of the dispersant. The slurry is allowed to settle for a pre-determined time as calculated from Stokes Law.

After settling for the prescribed time the supernatant solution containing the desired fine fraction is withdrawn, filtered and dried. By x-ray diffraction analysis of the fine fraction, it can be established if all of the abrasive components have been removed. Conducting the tests over a range of settling times will establish the point or size at which the abrasive components will be concentrated. If the size distribution of the silica fully over-laps the size range of the kaolin, then the sedimentation process, or any other method based on a difference in specific gravity, will not be effective for the separation of silica from kaolin.

It must be emphasized that the effectiveness of the separation technique is measured by the abrasiveness of the kaolin product as indicated by the Valley abrasion or Einhlener abrasion test (Newbold et al 1982, p.90). If the silica or other abrasive components are fine enough, the abrasiveness of the kaolin may fall within the required range. It is therefore not usual to specify the amounts of abrasive components that can be tolerated, but rather the abrasiveness of the material in comparison with commercially acceptable products. In general, higher abrasion values are tolerated for paper filling clays than for paper coating grades, assuming other properties of the kaolin are satisfactory.

Other techniques that can be employed for the separation of kaolin from abrasive components are differential flocculation and micro froth flotation. These techniques are more complex and require careful evaluation.

Fractionation of Kaolin

Kaolin slurries resulting from the primary process typically are too coarse in size for applications such as paper coating. It is therefore necessary to fractionate the slurry.

A number of different processes can be used to accomplish fractionation: Settling tanks, hydroseparators, hydrocyclones or decanting centrifuges are used (Figure 14).

Settling tanks or hydroseparators were the original equipment used. However, they have been largely phased out and replaced with the more efficient hydrocyclones and decanting centrifuges. Both these latter processes depend on the increased sedimentation rate in the centrifugal field. In each case, coarse particles are separated from fine particles and each fraction discharges as a separate stream. The separation point is controlled by the diameter of the hydrocyclone, the pressures, centrifugal acceleration and solution density. The separation in decanting centrifuges is controlled by the bowl speed and the feed rate to the centrifuge. Several stages of separation will normally be required. The process also allows production of several grades, such as No. 1 and No. 2 coating grade, filler grade and possibly a ceramic or rubber grade.

Bleaching of Kaolin

Following fractionation the kaolin may not have the desirable brightness required for paper coating grades. Clays are often discoloured by coatings of iron oxides or hydroxides and the presence of discreet iron bearing particles. Kaolin from primary deposits tends to be of higher brightness that the kaolin from secondary deposits.

Chemical bleaching is used to improve the brightness by the addition of chemicals to the slurry. Many different bleaching processes have been developed, each designed to achieve the required degree of brightness for a certain type of kaolin and contamination. Sodium or zinc hydrosulphite are two chemicals, in combination with sulfurous acid, that are effective bleaching agents. However, each type of kaolin may respond differently, and if the results are not satisfactory with the standard bleach procedure, alternative methods will need to be developed.

Sometimes low brightness is caused by very fine iron or titanium particles and bleaching alone will not be sufficient. Wet high intensity magnetic separation (WHIMS) has been successfully applied in these cases.

Magnetic Separation

Wet high intensity magnetic separation has been used for a number of years in the beneficiation of industrial minerals. Improved equipment and technique has recently been successfully applied to the beneficiation of kaolin clays.

Magnetic separation has proven particularly successful with grades of kaolin that otherwise do not respond to conventional bleaching techniques. It allows the mining of marginal and submarginal grades, and has reportedly doubled the useful reserves of kaolin in Georgia (Iannacelli 1980).

Two types of wet magnetic separators have been employed for kaolin: The first type is the "wet high intensity magnetic separator" (WHIMS); the other type is called the "high gradient magnetic separator" (HGMS). High gradient magnetic separation is discussed in the paper by Watson (1979, p.70-76). Wet high intensity is discussed by Isrealson (1978, p.211-219).

Magnetic separation is now an accepted process in the beneficiation of kaolin. It results in products of better brightness, and in many cases, can upgrade marginal or submarginal grades to acceptable products. Bleaching may still be required and is used in conjunction with magnetic separation and other purification techniques.

Delamination

Kaolin is a mineral of naturally fine particle size. Individual kaolin particles are often finer than two microns. Kaolin is a flake-type mineral with a high aspect ratio (ratio of mean diameter over thickness) of approximately ten. Often the kaolin plates are stacked together like a deck of cards, with the flakes held together by high cohesive forces. Many of the so-called coarse flakes are in effect stacks of fine particles, which because of their greater mass, are perceived as coarse particles. This can be effectively shown by electron microscopy. W.T. Maloney discovered that kaolin particles under two microns differed in physical properties other than size. This is described in U.S. patent 2,158,987.

Paper coating grade kaolin consists of kaolin with 80 to 90 percent of the particles finer than 2 microns. Most clays contain less than 60 percent of particles smaller than 2 microns. The knowledge that the particles coarser than 2 microns in many cases consist of fine particles stacked together has led to the development of processes for delaminating the kaolin stacks, thereby increasing the yield of paper coating grade kaolin (Figure 15).

Several processes have been developed for the delamination of kaolin. High shear forces are required to achieve effective delamination, so in general the delamination processes are energy intensive.

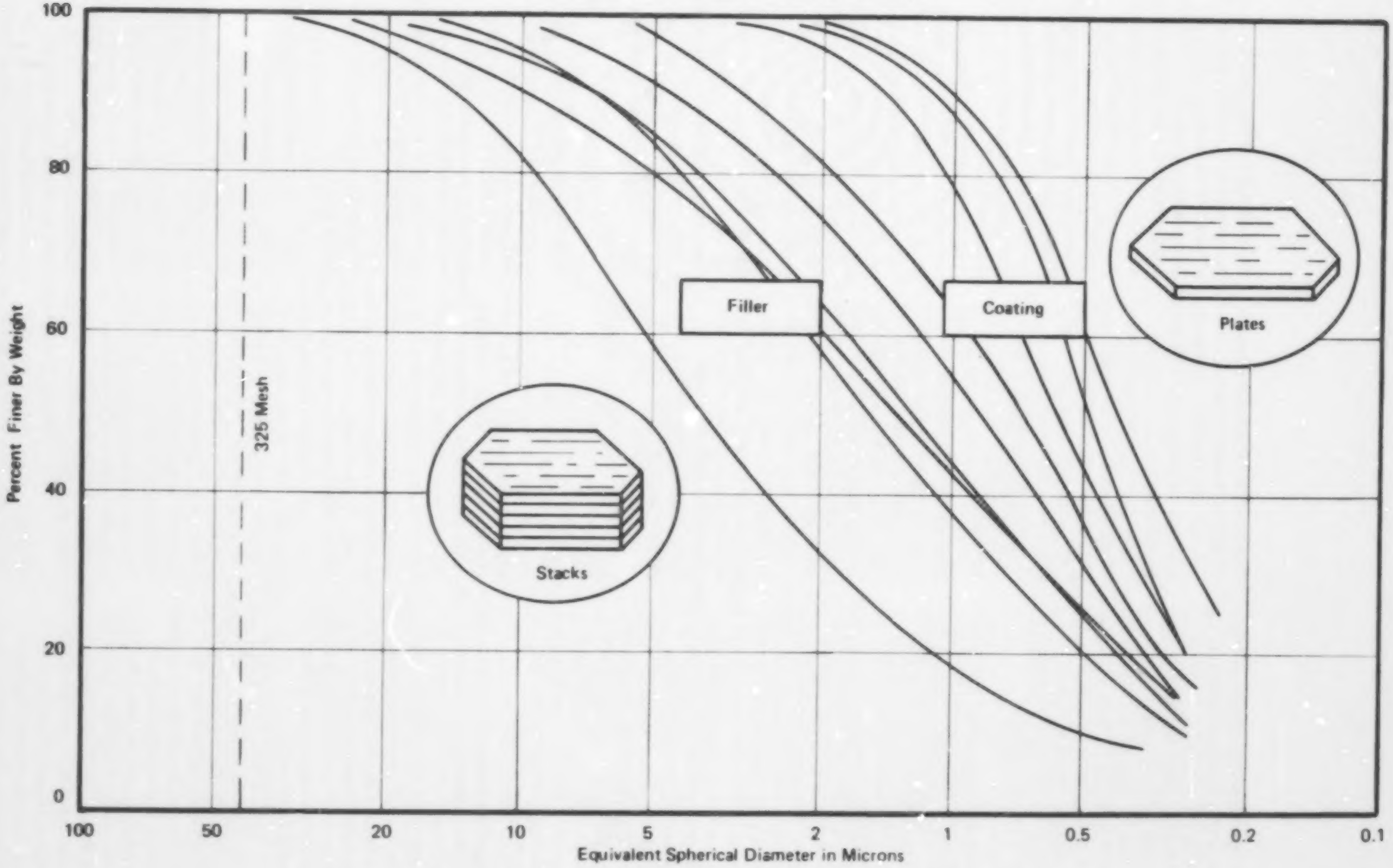
Delamination of kaolin stacks can be accomplished by high shear agitation of a kaolin slurry with nylon pellets or beads at optimum slurry density. To achieve effective delamination it is important to first remove the bulk of the 2 micron particles contained in the feed slurry; a feed slurry containing less than 20 percent of particles finer than 2 microns is recommended. The coarse fraction is then delaminated by high shear forces in the delaminator vessel using nylon or other plastic balls as the delaminating media.

Newly produced minus 2 micron material causes the system to become lubricated, with a corresponding loss of shear forces. It is therefore necessary to remove these fine particles by fractionation with centrifuges or hydrocyclones, recycling the oversize to the delaminator.

Such delamination, while effective, may result in kaolin products with different rheological properties (i.e. viscosity) than the paper coating grades produced from naturally occurring minus 2 micron fractions.

Other delaminating methods used include pug mills and extruders. The coarse kaolin, after removal of the minus 2 micron particles, is dewatered, mixed with dry clay and pug milled at 75 to 85 percent solids. The putty like mass is then extruded through a die with holes ranging from 0.5 to 12mm in diameter. A flocculant may be added to the clay slurry to facilitate the dewa-

KAOLIN PARTICLE SIZES FOR PAPER



SOURCE : INDUSTRIAL MINERALS AND ROCKS, 1975
FIGURE 15

tering process prior to pug milling. After milling and extrusion the kaolin is dispersed in water followed by removal of the newly formed 2 micron particles. The coarse fraction from this separation may be recycled to the system for further delamination.

Kaolin produced by this delamination process has good viscosity characteristics.

Delamination by either of these processes results in kaolin with higher brightness; platelets that were stacked together have not been exposed to contaminants and are therefore clean and white.

Delamination therefore has a multiple function. It increases the yield of paper coating grades and produces products with high brightness. It also improves the overall utilization of the crude kaolin, reducing the waste fraction and increasing the average value of products extracted.

The need for delamination will be self evident from the particle size distributions of the crude kaolin. However, the best process and optimum conditions for delamination must be established experimentally.

Organic Contaminants

Crude clays may be contaminated with organic substances or minerals like graphite, and they are not readily removed during preliminary processing, fractionation or bleaching. Because such substances reduce the brightness of kaolin their removal is important.

These contaminants, have naturally hydrophobic surfaces, ie. they are not easily wetted in an aqueous system, but they can be readily wetted by organic liquids. A process was developed by H. Morris and J.P. Oliver (U.S. patent 3,439,801) in which kaolin slurry is mixed with a water insoluble, non ionizable organic liquid. The kaolin remains in the aqueous phase while the organic contaminants concentrate in the organic phase. The clay is recovered in the aqueous phase after allowing the phases to separate.

Other methods for removal of organic components other than graphite include oxidizing the clay slurry with a strong oxidizing agent such as sodium hypochlorite, sodium chlorite, hydrogen peroxide or sodium peroxide. This is described in U.S. patent 853,095 by J. Iannicelli, A.C. Kunkle and R.N. Maynard.

Dewatering and Filtration

Kaolin is normally processed at low solids densities. The clay slurry must therefore be treated to remove as much water as possible before drying. This is usually done in two steps.

First a flocculant is added to the dispersed slurry. The flocculant can be an acid, a salt of an acid or a neutral salt, or one of a group of organic flocculants. Flocculation causes the kaolin particles to coagulate, and the coagulated kaolin will settle more rapidly in the solution because of increased mass.

The flocculated suspension can be settled in thickeners, or by treatment with disc-nozzle type centrifuges. The thickened slurry is then filtered on vacuum drum filters, filter presses, continuous belt filters or tube type filter presses. filter presses or tube presses are preferred; tube presses can achieve moisture levels of 17 percent.

The filter cake may be pug milled and extruded at this stage if delamination is required. If not, the filter cake is ready for drying.

Today many kaolin producers ship their paper coating grade kaolin as a 70 percent solids slurry. This has advantages to both the producer and the user: The slurry arrives ready for use in paper coating applications and the producer does not have the cost of drying.

Drying

Filter cake contains (depending on the filtration method) up to 25 percent water, and must therefore be dried before storage, bagging or bulk shipping unless shipments are to be made in slurry form.

Many different drying methods have been employed by kaolin producers, including air drying in a drying shed, belt dryers, flash dryers and spray dryers. The last three are most commonly used. Microwave drying would appear to offer some potential.

Kaolin processing is energy intensive, particularly the dewatering and drying stages. Continuous efforts are being made by the industry to reduce the energy component of the process (Clark 1980).

Wet processing of kaolin is mandatory for paper coating grades. However, paper filling, ceramic and rubber filling clays can often be produced from secondary deposits by dry processing methods. Kaolin from primary deposits is almost always treated by wet processing methods.

Dry Processing

Dry processing of kaolin is usually sufficient to produce ceramic, rubber and paper filling grades if the deposit is secondary and contains high amounts of kaolin with a minimum of abrasive minerals and other contaminants. Selective mining and blending is used to obtain suitable feed stock.

Lump clay is transferred by truck to the plant where the lumps are reduced in shredders or by other suitable means to 5 to 8cm. The clay is then dried in a rotary dryer and pulverized or ground in roller mills equipped with internal classifiers. During the classification, coarse grit and other contaminants are discharged by the classifier. Classification can also be accomplished by dedicated classifiers wherein the clay is ground in a mill or pulverizer and the product air classified. The primary function of the classifier is removal of grit and other coarse particles.

Products are stored in large silos from where they can be shipped in bulk or in bags by rail or truck.

Kaolin produced by dry processing usually closely reflects the properties of the crude kaolin. The dry process is simple and relatively inexpensive; in general it produces products of lower quality and value than those produced by wet processing.

Calcined Kaolin

Calcined kaolins are used in paint, paper, plastics and rubber. Calcination improves many of the properties of kaolin such as brightness, whiteness, oil absorbtion and electrical resistivity. It also increases the abrasiveness.

In the calcination process, kaolin products produced by wet processing are calcined at temperatures up to 1000°C to drive off the water of hydration from the kaolin.

Calcined kaolins are becoming popular as an extender or spacer for high priced titanium dioxide in many industrial applications, in particular paints, paper and plastics. Calcined kaolin provides good hiding power and opacity in coatings, and good electric resistivity in plastics used for such purposes as cable and wire coatings.

Surface Treated Kaolin

As is the case with many mineral fillers, surface treatment with specially developed organic chemicals will improve the performance of air floated, water washed or calcined kaolins. Water washed or calcined kaolins are the types most often treated. Stearates and various types of silanes are normally used.

The surface coating of minerals is a specialized technique, and most manufacturers develop their own methods and consider them proprietary. In general, the surface coatings are applied in high shear mixers such as the Henshel Mixer which is of the semi-continuous

Table 14 Major Kaolin Filler Applications

APPLICATION	FUNCTION	GENERAL SPECIFICATIONS
Paper Coating	Provides good gloss, smoothness, ink receptivity and opacity. Accounts for 15 to 25% of weight of paper. Calcined grades are used in paper coatings as an alternative to titanium dioxide extenders.	High brightness, 85-92 GE; 80-90% finer than 2 microns; low abrasiveness; good high and low shear viscosity at high solids levels. Wet processed kaolins are used exclusively and sold as No. 1, 2 and 3 coating grades.
Paper Filling	Fills interstices between the fibers; providing body to the paper. Reduces cost of paper; has excellent retention rate; used in coated or uncoated papers. Accounts for 5-15% of paper weight.	Good brightness, 80-84 GE; 60-70% finer than 2 microns; low abrasiveness; good rheological properties; dry or wet processed depending on application.
Paint	Used extensively in interior trade paints such as water based latex flat wall paints and industrial paints. Calcined kaolin is an effective TiO_2 spacer. Kaolin provides good application properties; contributes to hiding; enhances paint stability.	Good brightness; fine particle size; low abrasiveness; good dispersability and flow properties. Wet processed kaolins are used; lower brightness kaolin is used in industrial primers.
Plastics	Used in polyesters, polyethylene, polyurethane, P.V.C. Primary function is to reduce cost, i.e. extend the resin. Kaolin has good moulding characteristics and aids in viscosity control of polymers; improves tensile strength, electrical properties and dimensional stability of moulded parts.	Fine particle size, free of grit. Both wet and dry processed kaolins are used. Calcined kaolin or surface modified kaolins are used in special applications.
Rubber	"Hard" kaolin is used to reinforce rubber goods; it improves the tensile strength, abrasion resistance and provides high cured stiffness. "Soft" kaolin has poor reinforcing properties and generally reduces elasticity, tensile strength and abrasion resistance.	Air floated, dry process "hard" kaolin is used as a filler rubber.

Table 15 Minor Kaolin Filler Applications

APPLICATION	FUNCTION	GENERAL SPECIFICATIONS
Adhesives	Used as filler in various types of adhesives. The primary function is to reduce cost. Kaolin aids in viscosity control and aids in the suspension of other components.	Fine particle size. Water washed kaolins are used primarily.
Carpet Backing	Kaolin is used as a filler in natural rubber latex. It improves flexibility. Use of kaolin is diminishing due to competition with low cost calcium carbonates.	Medium to fine particle size; low brightness. Water washed or air floated dry processed kaolin is used.
Putty Caulks & Sealants	Kaolin is a minor filler in these applications. It controls viscosity, improves smoothness and sagging properties.	Wet process, high brightness kaolin is used in high quality products exposed to view. Dry process air floated kaolins are used in industrial type sealers and in dry wall jointing compounds.
Printing Inks	Kaolin improves viscosity and flow properties of ink. Used in publication and flexographic inks.	Water washed, high brightness kaolins.
Fertilizers	Surface coated kaolins are used in fertilizer, to provide anti-sticking and flow properties.	Amine coated dry processed kaolin.
Pesticides	Used as pesticide carrier for crop dusting or as a diluent.	Good dispersion and suspension properties; high sorbtive capacity. Minus 325 mesh dry process kaolin is used.

Table 16 Major Non Filler Applications for Kaolin

APPLICATION	FUNCTION	GENERAL SPECIFICATIONS
Ceramics	Used in virtually all types of ceramic products, including tile, sanitary ware, stoneware, electrical insulations, dinnerware and fine china. Kaolin is used in conjunction with ball clays.	Good fired colour; high green and dry strength; good casting and pressing properties, high fired strength. Both dry and wet processed kaolins are used.
Fiberglass	Kaolin is used as a batch ingredient in the production of textile type fiber-glass and is a source of alumina and silica in glass.	Minus 325 mesh, high purity kaolin, low in alkali compounds.
Refractories	Calcined kaolin is used in production of light and medium duty firebrick.	Wet or dry processed, extruded and calcined. High alumina preferred.

batch type. Pin mills can also be employed for surface coating.

Uses, Specifications, Prices

Of all the industrial minerals used as fillers, kaolin is used in the greatest volume. It is an important industrial commodity which has no suitable substitute for many of its applications.

The paper industry is the largest consumer of kaolin products; kaolin is used in paper filling and paper coating. It is used in paints, plastics, adhesives, rubber, ceramics, refractories, insecticides, food additives, foundries, floor tiles and textiles to name just the most important applications.

The accompanying tables provide a summary of its important filler and non-filler applications.

Paper

The paper industry is by far the largest consumer of kaolin. It is used extensively in paper filling and paper coating. For paper coating, water washed, delaminated and calcined kaolins are used. For paper filling, water washed or dry processed air floated kaolins are used.

The critical product requirements are colour of the kaolin, defined as brightness and whiteness, particle size, low abrasiveness and good high and low shear viscosity at high percentage solids.

Paper Coating Grades

Paper coating kaolin is broken down into four grades based on particle size, with each grade available as a normal or high brightness grade.

Water washed Fine Number 1 coating grade is the finest grade; it has a particle size of 95-100 percent finer than 2 microns and a G.E. brightness of 86-87 for regular and 90-92 for the high brightness grade.

Water washed Number 1 coating grade has a particle size 90-92 percent finer than 2 microns and a G.E. brightness of 86-88 for the regular grade and 89-91 for the high brightness grade.

Water washed Number 2 coating grade has a particle size 80-82 percent finer than 2 microns and a brightness of 85-87 for the regular grades and 89-91 for the high brightness grade.

Water washed Number 3 coating grade has a particle size 70-75 percent finer than 2 microns and a G.E. brightness of 84-86. This grade is usually only produced in the regular brightness grade.

The high brightness grades are considerably more expensive than the regular brightness grades with price differentials of about $40.00 U.S. per ton.

Grades and quality will vary from producer to producer. Hence, there are a great number of products within these grade designations.

Paper coating is usually performed in two steps:- a base coat, usually a coarser grade, followed by a top coat of the finer and possibly higher brightness grade. The weight of kaolin used for paper coating can be as much as 15 to 25 percent of the weight of the paper. The Number 2 and 3 coating grades are used for "publication" grade paper while the Number 1 and Fine Number 1 grades are used in special applications requiring high gloss, brightness and smoothness.

Prices

Coating grades are sold in 22.7kg (50 lb.) bags, dry bulk or as a 70% solids predispersed slurry. Most paper companies purchase in dry bulk or slurry form.

Prices range from U.S. $80 per tonne for the Number 3 coating grade to U.S. $103 per tonne for the Number 1 coating grade. The high brightness Fine Number 1 and Number 2 coating grades sell at a premium of approximately U.S. $40 per tonne.

Bagged grades sell for as much as U.S. $20 per tonne more than in dry bulk form. Slurried grades are priced below the dry bulk price, based on dry weight.

Paper Filling

Kaolin finds extensive application as a paper filling in coated and uncoated paper. Coarser, less bright grades are used. Most of the paper filler kaolins are produced by dry processing and are commonly referred to as air floated kaolin. Water washed grades are also used. Grades of lower brightness can be used for paper that is to be coated, while higher brightness is preferred for use in uncoated grades of paper.

Paper filling clays produced by the dry process are usually less pure; they contain more grit and are more abrasive than paper coating grades. Wet process filler clays are normally a by-product of coating grade production. Dry processing is usually only possible with clay from secondary deposits which contain a naturally high kaolin content. Primary deposits having low kaolin content are treated by wet processing.

The choice between wet and dry filler grade kaolins is based on cost and performance requirements in the particular application.

Filler grade kaolins have a G.E. brightness ranging from 70 to 84, with the lower values typical for the dry process grades. Particle sizes vary from 60 to 80 percent finer than 2 microns. Prices range from U.S. $40 to $60 per tonne in bulk. There is a wide range in quality as well as price.

Depending on type or grade of paper and other fillers used, kaolin is used in amounts of 5 to 15 percent of total paper weight.

Delaminated Kaolin

Deliminated kaolins are also used for paper coating. They have similar particle sizes to the coating grades, but higher aspect ratios which result in coatings of high opacity and brightness. Paper coatings made with delaminated kaolin are lighter in weight and hence particularly useful for lightweight papers.

Delaminated kaolins typically have particle sizes 80 percent finer than 2 microns, with some grades as fine as 95 percent finer than 2 microns. G.E. brightness ranges from 87 to 91.

Delaminated kaolin, like water washed kaolin, is sold in bags or in dry bulk and 70 percent slurry form.

Prices for delaminated kaolin range from U.S. $100 to $145 per tonne depending on particle size and brightness.

Delaminated kaolin commonly comprises 15 to 23 percent of total paper weight in coating applications.

Calcined Kaolin

Partly calcined kaolin is used by the paper industry primarily as an extender and partial substitute for more expensive titanium dioxide. Calcined kaolin sells for approximately U.S. $350 to $425 per tonne in 22.7 kg (50 lb.) multiwall bags f.o.b. the producer's plant.

Paint

The paint industry is a large consumer of kaolin as a pigment extender. Water washed, delaminated and calcined grades are used in "trade sales" and industrial paint formulations.

Water washed and delaminated kaolins are used primarily as a pigment extender in interior water-based flat wall paints and in the production of industrial metal primer paints. Calcined grades of kaolin are used in paints as a titanium dioxide extender in interior flat wall paints, traffic paint and other paints requiring high wear resistance.

There is no evidence that surface coated kaolins are of major benefit to the paint industry, and hence their usage is minor.

Dry processed kaolins, because of their low brightness, coarse particle size and potential presence of water soluble salts, are generally not used by the paint industry.

Water Washed Kaolin

Water washed kaolins are used in flat wall paints as a pigment extender in conjunction with other mineral extenders. Kaolin is easy to disperse in water, aids in viscosity control, and improves brushability and smoothness of the paint film. Because of its platy crystal structure it also contributes to the hiding power of the paint.

Kaolins of high brightness and fine size are preferred, and are sold in bags, bulk or slurry form.

Loading levels vary according to the type of paint produced and the required physical properties of the paint. In general, from 50 to 150 grams of kaolin are used per litre of paint (0.5 to 1.5 lb per gallon).

Prices

Water washed kaolins used in paints are priced in the range of U.S. $130 to $220 per tonne in 22.7kg (50 lb) paper bags. The price is proportional to the brightness and particle size of the kaolin; the finest and brightest grades are the most expensive.

All major kaolin producers market several grades of water washed kaolins, covering a range of brightness and particle sizes.

Delaminated Kaolin

Delaminated kaolins consist of particles with high aspect ratio, produced by special grinding or delamination processes from "coarse fraction" kaolins. These processes result in particles with large diameters but great thinness, having aspect ratios up to 40:1. Maximum plate size can be as high as 10 microns with plate thickness as low as 0.25 microns.

Delamination generally improves the brightness and particle shape, which in turn contribute to improved hiding power, flow characteristics, film smoothness, paint stability and tint retention.

Loading levels range from 50 to 150 grams per litre (0.5 to 1.5 lb per gallon) of paint, depending on the paint type and the properties desired.

Prices

Delaminated kaolin has a higher price structure than water washed grades because of higher production costs and enhanced paint properties.

Brightness and particle size govern the price structure. Prices range from U.S. $150 per tonne in bulk, for products with a G.E. brightness of 85 to 87, to U.S. $270 per tonne for the fine products with a G.E. brightness of 89 to 91, in 22.7 kg (50 lb) paper bags.

Products are sold in paper bags, bulk bags, bulk, and in high solids slurry form.

Most of the major kaolin producers offer delaminated kaolin products to the paint industry.

Calcined Kaolin

Calcined kaolins are produced by heating kaolin to approximately 800°C to drive off the water of hydration. Water washed or delaminated kaolin is used as feed stock for production of the calcined grade. The nature of the feed material, the particle size and variations in the calcination temperature will result in products with varying physical properties. In general the calcination process results in products with high brightness, improved electrical resistance, increased abrasiveness and lower oil absorption.

In paint, calcined kaolins are used to reduce the requirement for more expensive titanium dioxide (TiO_2), the prime pigment in paints. Calcined kaolin can substitute for part of the TiO_2 without loss of hiding power. Calcined kaolin has good hiding properties and because of its porosity can exhibit increased opacity.

Like water washed and delaminated kaolins, calcined kaolin is used in water based paint systems, mostly in flat latex wall paints. The coarser grades of calcined kaolin are also used in the production of traffic paints; its high abrasiveness aids in the production of flat non glare paints with good resistance to wear.

Usage is dependent on the type of paint and the desired end properties but in general ranges from 50 to 150 grams per litre (0.5 to 1.5 lb per gallon).

Prices

Production of calcined kaolin is an energy intensive process. High quality feed stocks such as water washed or delaminated kaolins are used to produce the premium grades.

Pricing is dependent on brightness and particle size with higher values for the brighter and finer grades.

Price range from U.S. $240 per tonne for coarser less bright grades to U.S. $500 per tonne for the finest and brightest products. All prices are based on 22.7kg (50 lb) paper bags in truckload quantities f.o.b. producer's plant.

Plastics

Kaolin is used in plastics primarily as a bulk filler to reduce the cost of the plastic compound. Water washed, delaminated and calcined kaolins in many cases each have specific product applications.

Water Washed and Air Floated Kaolin

The major application for water washed kaolin is in polyester and phenolics. In polyester it is used in bulk moulding compounds and sheet moulding compounds. Other than functioning as a resin stretcher, water washed kaolin aids in viscosity control of the mixture. Kaolin has good moulding characteristics and improves the surface quality of plastic parts.

Kaolin is used in phenolics as a replacement for short fiber asbestos. Water washed or air floated kaolins are used in this application. Kaolin improves the dimensional stability, electrical properties, water resistance and also provides some reinforcement.

Air floated grades of kaolin with low grit content are often chosen because of lower cost. In applications where abrasiveness cannot be tolerated, water washed grades are preferred.

Kaolin is typically used in combination with other fillers. For some applications the poorer colour of air floated kaolin is a deterent because it can affect the pigmentation of coloured plastic items.

Loading levels of kaolin can vary considerably and to some extent depend on the total filler loadings employed. Typical kaolin additions range from 5 to 30 parts of kaolin per 100 parts of polymer.

Prices

Air floated and water washed kaolin grades used in plastics are similar to the grades used in paper or rubber. The price structure reflects the degree of processing, brightness and particle size. Air floated grades range from U.S. $60 to $75 per tonne in 22.7kg (50 lb) plastic bags, while water washed grades suitable for plastics range from U.S. $155 to $225 per tonne in 22.7kg (50 lb) paper bags.

Delaminated Kaolin

Delaminated kaolin is not a frequently used filler in plastics. It has a better colour than air floated or water washed kaolin and also has greater reinforcing properties in some polymer systems. Increased tensile strengths have been reported as a result of the use of delaminated kaolin.

Calcined Kaolin

Calcined kaolin is a commonly used filler in polyvinyl chloride (P.V.C.) wire and cable compounds. Calcined kaolin imparts excellent electrical properties to P.V.C. and therefore it can be termed a functional mineral filler.

Calcined kaolin can be used at loading levels ranging from 10 to 30 parts of filler per 100 parts of resin.

Prices

Suitable grades of calcined kaolin are priced at U.S. $250 to $300 per tonne in 22.7kg (50 lb) paper bags.

Surface Coated Kaolin

Water washed, delaminated or calcined kaolins are used as feed stock for the production of surface coated kaolins. Surface coated calcined kaolin is used primarily in nylon and less frequently in low density polyethylene.

In nylon, the kaolin filler functions not only as a resin extender but it also improves a number of physical properties such as stiffness, mold shrinkage and sensitivity to moisture. It also reduces stress cracking. In polyethylene, the use of surface coated kaolin improves the heat deflection temperature. Surface treatment usually consists of coating the kaolin with polyfunctional silanes. Most nylons are processed at high temperatures, requiring surface coatings that will be stable at the processing temperatures employed.

Surface coated calcined kaolin is used in nylon at 20 to 40 parts of filler 100 parts of resin.

Prices

The price structure for surface coated kaolin reflects the complexity and cost of the processing. The products are marketed at prices ranging from U.S. $420 to $580 per tonne packaged in 22.7kg (50 lb) paper bags.

Rubber

Kaolins used in rubber are classified as to "hard" and "soft", terms employed in the rubber industry to distinguish certain critical properties.

Hard kaolin is a functional filler with reinforcing properties in rubber, while soft kaolin is used as a processing aid or as a filler in rubber goods not requiring reinforcement such as many household goods. Hard kaolins are used in high performance rubber such as automobile tires, footwear, cable and wire coatings.

Hard rubber grades of kaolin are produced from sedimentary deposits while soft rubber kaolins may be produced from either residual or sedimentary deposits. The hard kaolins are finer than the soft grades.

Kaolins used by the rubber industry are generally air floated or water washed grades, but some calcined and surface treated grades are used in special applications. Kaolin may be used with other natural or synthetic fillers.

Air Floated Kaolin

Soft air floated kaolins generally have a larger average particle size and lower brightness than water washed grades. They are used in soft rubber goods where reinforcing and good colour are not required. Grades with low grit content are preferred.

Hard air floated kaolin is finer than soft air floated kaolin but generally is also of low brightness. Hard air floated kaolin is the most common grade of kaolin used in rubber. It is used in a broad range of rubber products such as footwear, industrial and household products, and automobile tires.

Kaolin filler addition varies widely and is dependent on the application. In footwear, loadings of hard kaolin may range from 30 to 80 parts of kaolin per 100 parts of rubber, while in automobile tires and loading levels are 15 to 30 parts per 100.

Soft air floated kaolin is used at the rate of 100 to 200 parts of filler per 100 parts of rubber in soft rubber goods.

Prices

Hard and soft air floated kaolins are the least costly grades. Prices range from U.S. $40 to $75 in 22.7kg (50 lb) paper bags per tonne depending on colour, grit content and particle size.

Water Washed Kaolin

Water washed kaolins of fine particle size exhibit reinforcing properties similar to hard air floated grades. However, they have better colour, lower abrasiveness and fewer impurities; which allow their use in such applications as white sidewall tires, wire and cable coatings and light coloured housewares.

Use is limited because of competition from other fillers of high brightness and lower cost.

Prices

Water washed kaolin used in rubber is marketed at prices ranging from U.S. $150 to $180 per tonne in 22.7kg (50 lb) paper bags.

Calcined Kaolin

Calcined kaolin is used in rubber wire and cable coatings to improve the dielectric properties of the product. High brightness is not of great importance in this application and the calcined grades can be produced from air floated hard or soft kaolins.

Use of calcined kaolin in this application varies from 50 to 150 parts per 100 parts of rubber.

Prices

Prices range from U.S. $230 to $320 per tonne packaged in 22.7kg (50 lb) paper bags.

Surface Coated Kaolin

Surface coated kaolin is produced from water washed or calcined grades of kaolin. The surface coating improves dispersion and better bonding of mineral particles to the rubber, enhancing reinforcing properties. Silanes are commonly used for coating the kaolin.

The major benefits from surface coated kaolin are improved elasticity of the rubber and decreased deformation.

Prices

Surface coated grades of kaolin are expensive. Water washed coated grades are less costly than coated calcined grades. Prices range from U.S. $170 to $240 per tonne, for surface treated water washed, to U.S. $400 to $480 for surface coated calcined grades.

Adhesives

The adhesive industry used many different types of fillers. These are referred to by the industry as inert or inactive extenders. Of all the fillers used in adhesives, kaolin is used in greater volume than other natural mineral fillers.

Air Floated Kaolin

Of the various types of kaolin, air floated kaolin is the grade commonly used in low cost adhesives such as in construction, tile and panelling adhesives. Kaolin improves the troweling and flow properties of these adhesives, but its major function is to lower the cost of the product without reducing its effectiveness.

After rubber and paper, adhesives are the third largest volume application for air floated kaolins. High purity, low grit content and fine particle size is preferred by the adhesives industry.

Prices

Air floated kaolin used in adhesive applications is marketed at prices ranging from U.S. $50 to $70 per tonne, packaged in 22.7kg (50 lb) paper bags.

Water Washed Kaolin

Water washed kaolin is used in synthetic, vegetable or rubber based adhesives. Its prime function is cost reduction of the final product, while its secondary function is as a viscosity control and flow agent. Water washed kaolins are used in adhesives where colour is important. However, grades with high average particle size and lower brightness are commonly used.

Prices

Water washed grades of comparable high average particle size (2 to 5 microns) and low to medium G.E. brightness (80-84) are marketed to the adhesives industry at prices ranging from U.S. $130 to $170 per tonne in 22.7kg (50 lb) paper bags. The lower value products have an average particle size of 4 to 5 microns while the higher priced grades have an average particle size of 2 to 3 microns.

Delaminated and Calcined Kaolin

There is no apparent use of these grades in adhesives.

Surface Treated Kaolin

Only minor amounts of surface treated kaolin are used in adhesives. Their uses are as dispersion and suspension aids in liquid adhesives. Very fine (0.2–0.4 micron average particle size) kaolin is used as feed stock for production of surface coated grades.

Prices

Surface coated kaolin used in adhesive applications is sold for U.S. $400 to $600 per tonne in 22.7kg (50 lb) paper bags f.o.b. plant site.

Carpet Backing

Both air floated and water washed kaolins are used in carpet backing.

Air Floated Kaolin

Air floated kaolin is used in small amounts in natural rubber latex for carpet backing. Although lower cost grades are used, kaolin use is diminishing due to competition from other less costly fillers with lower binder demand.

Prices
Air floated grades used in carpet backing are sold for U.S. $50 to $60 per tonne in 22.7kg (50 lb) paper bags.

Water Washed Kaolin
Water washed kaolin is used in natural rubber or foamed latex systems to improve flexibility. Medium to fine particle size grades are used.

Prices
Water washed grades of medium particle size and brightness are sold at U.S. $130 to $150 per tonne packaged in 22.7kg (50 lb) paper bags.

Putty, Caulks and Sealants

Air floated, water washed, and calcined grades of kaolin are used in putty, caulks and sealants.

Air Floated Kaolin
Air floated kaolin is used in minor amounts as a filler in putty, caulks and sealants. The primary function is to reduce cost. However, the addition of kaolin also improves the application properties of the product. Poor colour and high binder demand makes kaolin vulnerable to white fillers such as calcium carbonate which has low binder demand.

Prices
Air floated kaolin is marketed in U.S. $55 to $65 per tonne in 22.7kg (50 lb) paper bags.

Water Washed Kaolin
Water washed kaolin is used in the more expensive types of putty, caulks and sealants such as bath tub caulk and other water based products. In these products kaolin aids viscosity, smoothness and ease of extrusion from tubes or cartridges.

Putty, caulks and sealants represent only a small market for kaolin. No specific grades have been developed for this application. Products of low average particle size (0.5 micron or less) with brightness of 85 G.E. are used.

Prices
Suitable grades are marketed at prices ranging from U.S. $200 to $350 per tonne in 22.7kg (50 lb) paper bags.

Calcined Kaolin
Calcined kaolin of high brightness is used in high quality putty, caulks and sealants as an extender for titanium dioxide. Grades similar to those used in paint are used in this application.

Prices
Calcined kaolin used in putty, caulks and sealants is marketed at prices ranging from U.S. $240 to $400 per tonne, depending on brightness and particle size.

Other Minor Filler Applications

Printing Ink
High brightness water washed kaolins are used in printing inks to control viscosity and flow properties. Primary use is in publication and flexographic inks.

Fertilizers
Air floated kaolins coated with amines are used in fertilizers as anti-sticking and flow conditioners. Only a small addition is required to prevent sticking and promote flow. Coarse, air floated kaolins are adequate.

Kaolin prices for this use are estimated at U.S. $70 to $100 per tonne. However, other minerals can fulfill the same function, and normally kaolin is ony used in areas where it is cost competitive with other products.

Pesticides
Kaolin is used as a carrier or diluent for presticides and insecticides for crop dusting and other applications. Dry processed kaolin with good absorptive capacity is used in this application.

Dry processed fine particle size kaolin suitable for this application is sold at U.S. $40 to $55 per tonne.

Production and Consumption

Kaolin comes close to being the ideal mineral filler. It has been said that if it had not been found in nature, it would have had to be invented! Kaolin enjoys great diversity in use and worldwide application.

Canadian Consumption
Canada imports nearly all its requirements of kaolin from the United States and United Kingdom. The record of these imports for the period 1969-1980 is reproduced in Table 17. The state of Georgia is the principal source.

Canadian consumption of kaolin is primarily in paper (Table 18). Its use is about equally divided between filling and coating grades (Table 19). Filled and coated paper may contain as much as 30 percent kaolin by weight, and since kaolin is about one-third the price of wood fibre, its use not only improves the quality of the paper but lowers its raw material cost.

Like Sweden and Finland, Canada is primarily a producer of pulp and newsprint, and hence is not a major market for kaolin. However, substantial growth in the Canadian production, consumption and export of coated paper has been forecasted (Carnell 1977, p. 92).

Production
Total world production of kaolin was nearly 18 million tonnes annually in 1979 and 1980. United States accounted for about 7 million tonnes, United Kingdom about 3 million and Soviet Union an estimated 2.5 million. Czechoslovakia, India and Brazil were also significant producers (Watson 1982 p.19).

Table 17 Canadian Imports of Kaolin

	TONNES	CAN. DOLLARS
1969	208,578	5,312,000
1970	215,510	5,598,000
1971	183,613	5,718,000
1972	210,457	6,324,000
1973	185,417	6,417,000
1974	181,223	7,418,000
1975	148,378	6,783,000
1976	176,751	7,340,000
1977	153,775	9,560,000
1978	181,887	12,935,000
1979	273,422	19,652,000
1980 P	254,354	21,836,000

P. Preliminary
Source: Statistics Canada

Table 18 Canadian Consumption of Kaolin By Use

	1969	1979 (preliminary)
	TONNES	
Paper and paper products	129,678	160,807
Rubber and linoleum	8,008	7,108
Paint and varnish	12,849	9,241
Ceramic products	2,553	9,847
Other products (eg. chemicals cleansers, pharmaceuticals)	9,748	20,978
	162,836	207,981

Source: Statistics Canada

Table 19 Canadian Consumption of Kaolin For Paper

	COATING GRADE	FILLER GRADE	TOTAL
1977–tonnes	80,000	75,000	155,000
–dollars	7,000,000	5,000,000	12,000,000
1978–tonnes	87,000	80,000	167,000
–dollars	8,500,000	6,000,000	14,500,000
1979–tonnes	91,000	83,000	174,000
–dollars	9,000,000	6,500,000	15,500,000

Source: Law 1979, p.26

In 1981 a total of 133 kaolin mines or pits were operated in twelve states of the United States. Georgia accounted for 18 percent of total U.S. tonnage and nearly all the paper grades; South Carolina contributed 9 percent (Ampian 1982 p. 2-3).

The record of kaolin production in the United States for selected years since 1933 is shown in Table 20. A breakdown of annual production by type of kaolin product is given in Table 21 for recent years. Waterwashed and calcined kaolins are the two types showing major growth.

Distribution of kaolin production in United States into the principal filler markets is given in Table 22; also shown are exports to the same markets. Total U.S. exports of kaolin were 1.28 million tonnes valued at U.S. $156 million in 1981. Major recipients were Japan (31%), Canada (15%), the Netherlands (13%) and Italy (11%) (Ampian 1982, p.4).

Estimated annual market for kaolin in the study area and in the total Canadian and United States markets is shown in Table 23.

Competitive Materials

The principal competition for kaolin is calcium carbonate. Expected conversion of the papermaking process to alkaline sizing by a substantial number of paper plants will favour a shift to calcium carbonate because of its lower price, and greater whiteness. For the same reasons calcium carbonate is also preferred in paints, although kaolin has better flow characteristics and hiding power.

For coating paper, precipitated calcium carbonate may compete with kaolin because of its higher brightness; but it is more expensive than kaolin.

Talc competes with kaolin in paint, where it has better brightness, hiding and flatting properties. It also competes in putty, caulks and sealants because of improved flow properties. Research into the possible use of talc as a paper coating pigment is continuing.

Precipitated silica, because of its extremely fine particle size, gives better reinforcing properties to rubber, and improved light scattering properties in paper. However, because of higher cost it is not widely used in place of kaolin.

Table 20 Kaolin Production in the United States

	TONNES	U.S. DOLLARS
1933	373,000	2,366,339
1943	843,000	8,067,322
1953	1,700,000	27,092,181
1963	2,869,000	59,770,274
1974	5,798,000	208,864,859
1978	6,325,000	367,782,408
1979	7,039,000	462,320,088
1980	7,146,247	527,098,609
1981	6,948,056	577,893,602

Source: Ampian 1982, Harben 1979.

Table 21 United States Kaolin Production By Type

	1977	1978	1979	1980	1981	Average 1981 value per tonne U.S. dollars
	Thousands of Tonnes					
Waterwashed	2,506	2,831	3,398	3,198	3,287	97.04
Calcined	1,023	1,079	1,278	1,502	1,356	108.89
Airfloated	1,271	1,312	1,156	1,413	1,189	47.45
Delaminated	381	361	325	398	427	102.07
Unprocessed	704	742	883	635	689	16.34
	5,885	6,325	7,040	7,146	6,948	83.17

Source: Ampian 1982, Harben 1979

Trends

Brazil is emerging as a major new source of high quality paper grade kaolin. However, the United States is expected to continue its dominant role in world kaolin production. The successful application of high-intensity magnetic separators to kaolin beneficiation has greatly enhanced the enormous reserve potential for Georgia kaolin.

Calcium carbonate is the only serious competitor for kaolin in filler applications. An expected shift in papermaking to an alkaline process will favour increased use of calcium carbonate. Nevertheless, growth of kaolin consumption is expected to continue, although perhaps at a slower rate. Much expansion, particularly in the

Table 22 U.S. Production of Selected Kaolin Fillers

	1980	1981
For Domestic Consumption	TONNES	
Adhesives	68,638	64,861
Linoleum and asphalt tile	10,652	4,494
Paint	149,111	69,808
Paper coating	2,273,492	2,181,793
Paper filling	873,941	1,074,858
Plastics	53,815	60,159
Rubber	251,342	188,344
	3,680,991	3,644,317
Exports		
Paint	23,123	28,477
Paper coating	627,142	548,096
Paper filling	70,763	74,571
Plastics	19,951	21,673
Rubber	40,862	39,384
	781,841	712,201

Source: Ampian 1982, p.9-10.

Table 23 Estimated Kaolin Filler Market, 1980-1985

	TOTAL CANADA AND UNITED STATES	STUDY AREA
	TONNES ANNUALLY	
Paper	3,400,000	2,200,000
Plastics, rubber	300,000	200,000
Paint	150,000	90,000
Adhesives	65,000	40,000
Inks	25,000	15,000
Linoleum, asphalt tiles, carpet backing, caulks and sealants	30,000	10,000
	3,870,000	2,555,000

production of waterwashed kaolin of high brightness is in progress in anticipation of increased needs for paper. And this in turn reflects forecasts of expanded production of coated paper worldwide.

Canada is not a major consumer of kaolin because it has been largely a producer of pulp and newsprint. Nevertheless, increasing demand for quality paper, and increasing cost for imported kaolin, is stimulating research into the suitability of Moose River kaolin deposits of northeastern Ontario.

7 Mica

Summary

The most unique property of mica is its platy habit, and the fact that mica "books" can be delaminated to flakes of high aspect ratio (ie ratio of diameter to thickness). The toughness, yet thinness, of these flakes gives mica great reinforcing properties in filler roles. Mica-reinforced plastics are expected to experience major growth in the automobile industry at the expense of steel; if so, mica will enjoy the fastest growth rate of any mineral fillers in use today. Muscovite is preferred because of its neutral colour.

Traditional uses for mica flakes grew out of the early insulating and electronic markets for mica sheets. Waste mica from the trimming of sheets was readily available and some success was achieved in reconstituting these for sheet markets. However, other synthetic materials and new technology have all but eliminated the market for natural sheet mica.

Traditional markets for mica flakes include its use in oil drilling fluids to plug porous rock horizons and to maintain fluid circulation; as a filler in paints, gypsum wallboard and joint cements; and as a dusting agent to facilitate mould release in rubber manufacturing and to prevent sticking in rolled roofing. More recently, mica flakes have been successfully substituted for asbestos in various asbestos-cement applications. Indeed, mica is a major contender in a number of markets where alleged health hazards have discouraged the use of asbestos.

Commercial sources of flake mica in North America are concentrated in southeast United States, particularly North Carolina, where it is produced as a by-product of feldspar and lithium mining, or as a coproduct in the hydraulic mining of deeply weathered granitic rocks. Phlogopite from a schist deposit in Quebec is produced as a primary product by Martin Marietta, and much of the development work on mica-reinforced plastics was sponsored by that company.

A large deposit of muscovite schist at Kaladar in southeastern Ontario was being tested by Koizumi Group (Canada) Limited in the early 1980's. Prospecting for other deposits of muscovite schist should be directed to similar metasedimentary terrains or acid igneous rocks.

Mica has yet to realize its expected growth in plastics. Meanwhile it is a low volume commodity, finding filler applications mainly in drywall compounds and paint. Its total filler market in the United States and Canada is estimated at 87,000 tonnes, of which about 40,000 tonnes are in the study area.

Geology

The term "mica" is a family name for a group of hydrated alumino-silicates whose most obvious physical characteristic is a perfect basal cleavage. Mica "books" result from the stacking of essentially two dimensional silicate layers. A weak ionic bonding between these layers allows for relatively easy separation of mica flakes.

There are many mica minerals, but the common ones are muscovite (white mica), phlogopite (brown mica) and biotite (black mica). They have the following chemical compositions:

Muscovite	$H_2KAl_3(SiO_4)_3$
Phlogopite	$H_2KMg_3Al(SiO_4)_3$
Biotite	$H_2K(Mg,Fe)_3Al(SiO_4)_3$

Although mica is one of the most common rock forming minerals, deposits of commercial interest are surprisingly rare.

Muscovite

Mainly because of its colour, muscovite is the most desired mica for filler uses. It is a common constituent of granite rocks and regionally metamorphosed gneisses and schists. It is also common as a weathering-resistant detrital mineral in clays and sandstones.

The traditional source of muscovite flakes has been as a by-product of the mining of sheet mica from granite pegmatites. While the demand for mica sheets for electrical insulators continues to decline, the industrial use of flakes is expanding. Hence alternative sources of flake muscovite, such as coarse grained granite "alaskite" (where it is a by-product of feldspar production), and kaolin deposits (as a by-product of kaolin production) have been utilized.

Regionally metamorphosed gneisses and schists, in which muscovite is a major constituent, are also being considered as commercial sources. Areas of low to medium metamorphic grade are preferred prospecting grounds because these rocks tend to exhibit simpler mineralogy and fewer mineral intergrowths; hence commercial beneficiation is easier and the mica product cleaner.

Sericite is a naturally fine-grained white mica, chemically and physically similar to muscovite. Sericite schists may also be of commercial interest for finely ground filler uses.

Phlogopite and Biotite

Phlogopite and biotite form a continuous series in which iron is progressively substituted for magnesium.

The black colour largely precludes the use of biotite as a mineral filler; also it does not as readily split into thin laminae. Biotite is a common constituent of acid to intermediate igneous rocks.

Phlogopite is typically amber-coloured or brown, and while muscovite is preferred for its neutral colour and superior electrical and optical properties, phlogopite has much greater thermal stability and so finds special applications where this is important. Phlogopite occurs in ultrabasic rocks and in dolomitic marbles.

Vermiculite is a hydrothermal alteration product of biotite or phlogopite that is characterized by its accordion-like expansion when flash-fired. In its expanded form it is used as loose-fill insulation, lightweight aggregate, and planting medium.

Ontario Deposits

The only mica that has been produced in Ontario on a substantial scale has been sheet mica for electrical and electronic applications. Historical records of production date from 1860 to 1953.

D.F. Hewitt (1967 p. 30-31) lists 63 muscovite occurrences, most of them pegmatite dikes, on which some work had been performed or production recorded. Of these the Purdy Mica Mine near Mattawa was by far the largest, producing muscovite sheets between 1941 and 1953 representing one-third of total Ontario production (Hewitt 1967, p. 25).

A total of 160 phlogopite mines are recorded in Ontario. According to Hewitt (1968, p. 1-2).

A large percentage of the Ontario phlogopite production came from the Lacey mica mine near Sydenham, which began operations about 1880 and produced intermittently until 1948. Partial production of the Lacey mine from 1900 to 1948 amounted to 5,781 tons of phlogopite valued at $827,756. Crystals up to 9 feet in diameter were produced. The principal phlogopite producing areas in Ontario were in Loughborough and Bedford townships in Frontenac county, and in North Burgess township in Lanark county near Perth.

Early descriptions of mica occurrences and the sheet mica industry throughout Canada are given by H.S. Spence (1929) and J.W. Hoadley (1960).

Few, if any, of the deposits worked for sheet mica would be of commercial interest for mica flakes today. Such deposits were generally too small and erratic, and the content of mica too low for commercial development for present markets. Nevertheless the quality of the mica in these occurrences was very high.

Kaladar Muscovite Schist

A large deposit of medium to coarse grained muscovite-quartz schist is being explored by Koizumi Group (Canada) Limited in lots 1 to 4, concession IV, and the west halves of lots 3 to 5, concession V, Kaladar Township, County of Lennox and Addington. The deposit consists of about 60 percent muscovite, the rest quartz with minor biotite and hematite. It strikes nearly north-south and dips at a moderate angle to the east. The deposit underlies low ground between more resistant ridges of quartz-biotite-garnet gneiss.

The muscovite schist zone varies from 30 m to more than 100 m in thickness and can be traced over a length of several kilometres. It forms part of the Claire River Syncline, a sequence of relatively low grade metasediments peculiar to this part of the Grenville Province. In 1982, Koizumi had completed a processing plant in Japan and was testing large bulk samples from the Kaladar deposit.

Clarendon Muscovite Schist

A large area between the villages of Fernleigh and Ardoch in Clarendon Township, Frontenac County, is underlain by muscovite-quartz schists containing variable amounts of biotite, plagioclase, garnet, staurolite, kyanite, sillimanite and magnetite. This is a zone of high grade metamorphism, and while the mineralogy may be more complex, there might be an opportunity to recover other mineral concentrates as by-products of a mica beneficiation process. It is an area worth further exploration.

Producers

The only substantial mica producer in Canada is Martin Marietta in Quebec. Mica production in the United States is primarily in the form of by-products from the mining of feldspar and lithium. Production of mica in Scotland has recently been initiated. India and Brazil continue to be important sources of sheet mica. Africa, Scandinavia, France and Spain are producers of flake mica.

Quebec

A large and unusual deposit of phlogopite was put into production in 1976, a joint venture of Marietta Resources International Limited and Societé Minéralurgique Laviolette, Inc. The mica is sold under the trade name "Suzorite" after Suzor Township in which it occurs. It is located nearly 500 km by rail north of Montreal.

The main deposit, and other similar occurrences nearby, are nearly vertical lenses of coarse grained phlogopite, which comprises 85 to 90 percent, with minor feldspar and pyroxene, and traces of apatite, calcite, chlorite and opaque minerals. Some 20 million tonnes have been proven in the main deposit, which is 330 m long by up to 60 m in surface width. The deposits occur in high grade metasedimentary terrains intruded by a variety of igneous rocks.

The deposit is easily worked by quarrying, and the crushed material is shipped by rail to a processing plant at Boucherville near Montreal. Plant capacity is about 30,000 tonnes per annum. A number of products are produced ranging from a coarse flake product for use in drilling fluids to seal porous rock strata, to very fine products of high aspect ratio for use as reinforcing fillers in plastics.

United States

The United States is the leading world producer of mica flakes much of which are coproducts of feldspar, kaolin and lithium mining. Sources in North Carolina account for about two-thirds of the United States total. The rest is from Connecticut, Georgia, New Hampshire, New Mexico, South Carolina, South Dakota, and Texas (Table 24). In 1982 there were fourteen producers of mica flakes of which seven were major suppliers of mica fillers.

Table 24 Mica Producers in United States, 1983

Company	**Parent Company**
North Carolina	
English Mica Co. & U.S. Mica Co.	Kings Mountain Mica Co. Inc.
U.S. Gypsum	—
Harris Mining Co.	Blue Diamond Coal Co.
Feldspar Corp.	Pacific Tin Consolidated Corp.
Lawson-United Mineral Feldspar Co.	Indusmin Ltd.
Deneen Mica Co.	—
Asheville Mica Co.	—
Lithium Corp. of America	Gulf Resources and Chemical Corp.
J.M. Huber Corp.	—
Franklin Mineral Products	Mearl Corp.
Foote Mineral Co.	Newmont Mining Corp.
South Carolina	
Spartan Minerals Corp.	Lithium Corp. of America
Mineral Mining Corp.	—
New Mexico	
Mineral Industrial Commodities of America Inc.	—
Texas	
Alamo Mining Corp.	—
South Dakota	
Pacer Corp.	—
New Hampshire	—
Concord Mica	
Georgia	
Franklin Mineral Products	Mearl Corp.
Connecticut	
Feldspar Corp.	Pacific Tin Consolidated Corp.

Reference: G. Clarke 1983, p. 29, with modification.

Note: Wet ground mica producers are members of the Wet Ground Mica Association Inc., with headquarters at 60 Rock Harbour Road, Orleans, Massachusetts, 02653. This trade organization conducts or supports research studies for its members to further the use of mica in industrial applications.

North Carolina

Two areas are important for mica: The Spruce Pine area of northwestern North Carolina, and the Kings Mountain area of west central North Carolina.

Spruce Pine Area

Pegmatites of the Spruce Pine area have been historically important for the production of both sheet mica and feldspar. Now, however, the parent intrusive granitic rock "alaskite" is the principal source of feldspar and flake mica. Average composition of alaskite is approximately (Parker 1952):

Mineral Composition of Alaskite

		Percent
Feldspar:	plagioclase	45
	microcline	20
Quartz		25
Muscovite mica		10

Muscovite mica is produced both as a by-product of feldspar mining of relatively fresh alaskite and as a primary product from the mining of deeply weathered portions. In the latter case, deposits of weathered alaskite up to 30 m deep are excavated by power equipment or hydraulic methods and the mica is concentrated by coarse screening, screw classifiers, and in the finer sizes by flotation (Industrial Minerals, July 1976, p. 23).

Companies producing mica from the Spruce Pine area include the following:

U.S. Gypsum Company

U.S. Gypsum is the leading producer of mica for filler applications. In 1979 it purchased Diamond Mica Company which operated two plants in the Spruce Pine area: one with an annual capacity of about 7,000 tonnes of dry-ground mica; the other about 12,000 tonnes of wet-ground mica. The wet plant has been converted to a dry process with substantially increased capacity. U.S. Gypsum also operates a plant at Kings Mountain, North Carolina, acquired from Western Mining Company in 1965. Total grinding capacity is estimated at 32,000 tonnes per annum (Clarke 1983, p. 30), much of which is sold or used captively for dry-wall compounds and paints; plastics and rubber are its other markets.

Harris Mining Company

A division of Blue Diamond Coal Company, Harris produces kaolin, mica and quartz by wet beneficiation and flotation of its weathered "alaskite" deposit. It is an important supplier of muscovite mica for dry-wall compounds, also with minor sales for oil well drilling, roofing, paints and plastics. Plant capacity is about 22,500 tonnes per annum.

Kings Mountain Area

The Kings Mountain area is known for its spodumene pegmatites. The pegmatites are unzoned and have the following average composition (Kesler 1961):

Mineral Composition of Kings Mountain Pegmatites

	Percent
Feldspar (albite, microcline)	41
Quartz	32
Spodumene	20
Muscovite	6
Trace Minerals	1

Mica is produced both as a by-product of lithium (spodumene) mining of pegmatites and as a coproduct with feldspar, silica sand and brick clay in the mining of weathered deposits.

Companies producing mica from the Kings Mountain area include the following:

Kings Mountain Mica Company Inc.

This company operates the former English Mica Company and U.S. Mica Company Inc., producing both wet and dry-ground mica products which are still sold under their original trade names for use in dry-wall compounds and other filler uses. The company also produces feldspar, silica sand and a low-grade kaolin clay for brick-making. Mica capacity is about 16,000 tonnes per annum.

Foote Mineral Company

Foote Mineral Company produces by-product feldspar, feldspathic sands and mica from its lithium mine at Kings Mountain. A cluster of eight spodumene pegmatites is mined in a single quarry excavation.

Lithium Corporation of America

Spartan Minerals Corporation, a subsidiary of Lithium Corporation of America, produces feldspar and muscovite mica as by-products of spodumene mining of a large pegmatite at Cherryville in the Kings Mountain area of North Carolina. The pegmatite deposit extends over a considerable length and is up to 90 m wide.

Other Producing States

The main producer in Georgia is Franklin Mineral Products Company Inc., which operates a mine and plant at Wilmington and supplies wet-ground mica to the paint and cosmetics industries.

Pacer Corporation mines two pegmatite deposits in South Dakota at Custer and Keystone. Potash feldspar, muscovite mica, high purity quartz and spodumene are produced in the Custer mill. Potash feldspar, crude mica scrap and quartz is produced at Keystone. Both plants use dry process methods. About 90,000 tonnes of low grade mica (70% muscovite, 30% biotite) are produced annually for oil drilling (Clarke 1983, p. 32).

Feldspar Corporation produces a muscovite flotation by-product from its pegmatite feldspar operations at Middletown, Connecticut, and Spruce Pine, North Carolina. Total annual production of about 15,000 tonnes is sold to U.S. Gypsum.

A substantial amount of impure sericite is used in brick-making for decorative effects. In South Carolina sericite is produced by the Ashe Brick Company, the Broad River Brick Company and Carolina Ceramics; Mineral Mining Corporation produces sericite for paint filler.

MICA (Mineral Industrial Commodities of America) is a major producer of muscovite at Santa Fe, New Mexico, from quartz mica schist. New flotation and dry grinding facilities will give the company a mica capacity of about 36,000 tonnes per annum (Clarke 1983, p. 32) mostly for dry-wall compounds.

United Kingdom

In 1980 a new mica mine was developed near Pitlochry in the Scottish Highlands as a joint venture of Sir Alfred McAlpine and Sons Limited and Microfine Minerals and Chemicals Limited. The quarry is developed in a mica-quartz-garnet schist and products of all three minerals are produced, including both muscovite and biotite. Grinding and beneficiation is entirely dry.

Although muscovite was formerly produced as a by-product of kaolin mining in Devon, the Pitlochry mine is currently the only mica source in the U.K.

Mining Methods

Early commercial interest in mica was mainly for mica sheets for use as thermal windows in stoves and lamps, and as electrical insulators in motors, generators and vacuum tubes. Pegmatites were the source of large mica sheets and books, and these were typically mined by a few individuals using a minimum of powered equipment. The sporadic distribution of mica pockets in pegmatite generally resulted in irregular mine workings, usually of the shallow open-cut variety.

In rare instances deposits were attractive enough to warrant underground development. Such was the case with the Purdy mica mine east of North Bay, Ontario, the largest producer in Canada and one of the outstanding sources of muscovite sheets in North America. Based on a number of individual dikes to 6 m in width and 100 m in length, the deposits were first worked by open cuts but eventually also by stoping and drifting from an adit in a hillside (Hewitt 1967, p. 31-35).

Because of the fragile nature of the mica crystals, a minimum of blasting was employed. After freeing the mica books by prying and wedging, great care and judgment was needed in the trimming and rifting operations to minimize waste and maximize the usable area of the crystal. The product was valued on the basis of size, quality and clarity.

Initially serving a small market, but one which has steadily grown while the demand for sheet mica has declined, scrap mica unavoidably produced in the trimming process has become an important mineral filler and an additive in drilling muds. These uses have also encouraged the recovery of flake mica as a by-product of feldspar and lithium mining where the tenor of mica in pegmatite and granitic (eg. alaskite) deposits is relatively low. In recent years there has been increased interest and some development in deposits of mica schist, where mica content may exceed 50 percent; also in deeply weathered residual granitic deposits and clays which lend themselves to inexpensive hydraulic mining.

The mining of feldspar, lithium and their by-products, including mica, from massive granitic rocks and pegmatites is typically accomplished by quarrying. Overburden must first be thoroughly removed, usually by powered equipment: self-propelled scrapers, bulldozers, shovels and front-end loaders. Final cleaning of the rock surface may require hand shovels or hydraulicing. Large deposits are worked in benches, each 10 to 15 m thick, using conventional quarrying equipment and truck haulage to the primary crusher. Hard mica schists are worked in a similar way.

Residual deposits of micaceous rocks may lend themselves to hydraulic mining or excavation by loaders, power shovels and bulldozers. Hydraulic mining is attractive in deeply weathered deposits because it facilitates disaggregation of the weakly-bonded mineral constituents and improves the screening and washing operations.

Processing Technology

In North America, mica production has been largely a by-product of feldspar and kaolin production. However, recent developments in the use of mica as a reinforcing filler in plastics has focussed attention on the production of mica as a primary product. The use of mica as a filler in plastics has been researched extensively by Dr. Raymond T. Woodhams of the Department of Chemical Engineering, University of Toronto, who is one of the pioneering investigators of the use of mica in plastics. Current interest in mica as a reinforcing filler has generated interest in deposits of flake mica where the mica is the sole mineral constituent of commercial interest.

Micas of commercial interest are generally muscovite or phlogopite. Biotite mica, because of its dark colour, is not a major consideration for industrial applications.

Much of the published literature on mica processing deals with the separation of mica from minerals such as feldspar or kaolin. Mica in many instances is dealt with as a contaminant to be removed in order to achieve purity in some other mineral commodity.

In the feldspar industry mica is separated from feldspar by the froth flotation process. In the kaolin industry mica is recovered during the degritting process, followed by further purification of the mica if necessary. Froth flotation is one of the primary separation processes to be considered in the treatment of such mica sources as mica schists, phyllites, pegmatites and granites. A number of froth flotation methods have been developed and are referenced in the bibliography on mica in this report.

For most of the industrial applications in which mica is used it is only necessary to grind and size mica concentrates. Both dry and wet grinding are employed, with dry grinding the most common method. Wet ground mica is preferred in applications such as paint extenders and mica paper. Wet grinding retains and enhances the lustre of muscovite mica and does not roughen or damage the edges of the mica flake.

Primary Processing

The processing of mica-bearing rocks follows the normal pattern of primary and secondary crushing, common to most industrial minerals. Equipment selection for the crushing stages is dependent on the type of material to be treated. Feldspars, granites or pegmatites are usually crushed with gyratory or jaw crushers as primary crushers, while cone crushers are used as secondary crushers. Mica schists are crushed in a similar manner; however, impact crushers may be preferable for secondary and tertiary crushing.

Grinding of mica-feldspar mixtures is by wet rod or ball milling. Soft mica schists can be processed by impact crushers, cage mills, etc. to achieve liberation of mica flakes from the gangue minerals.

Dry Grinding

High speed hammer mills, pin mills, especially designed disintegrators or pulverizers are the most commonly used types of equipment for the dry grinding of mica. The grinding equipment is usually operated in closed circuit with air classifiers. The Szego mill was developed at the University of Toronto specifically for the dry grinding of mica.

Wet Grinding

An established method for the wet grinding of mica uses specially constructed chaser mills. These mills, lined with wood and using wooden grinding rollers, grind mica on a batch basis. This method prevents flake damage and tends to delaminate the mica (Industrial Minerals, July 1976, p. 19). Alternatives to this method are rubber lined attritor mills. Mica at a high solids ratio is ground by friction between particles, mill walls and the high speed rubber coated impellers. This process can be converted from a batch process to a continuous process by placing the desired number of attritors in series. The mica may be classified by screening, hydrocyclones or both. The classified mica is filtered in belt vacuum filters and dried on belt driers or with flash driers. Wet grinding may result in micas with flake aspect ratios of 30:1 or more.

Micronizing

For applications such as paint extenders it is necessary to finely grind the mica. Fluid energy milling is the most effective micronizing method. In this process mica is ground in a doughnut shaped mill, lined with high density ceramic materials. Super saturated steam or hot air at high pressure is introduced into the mill. Mica is fed to the mill via a venturi type feeder. It is accelerated to supersonic speed, causing collision of the particles with each other, and with the walls of the mill. Centrifugal action causes coarser particles to assume a trajectory along the outside circumference of the mill, while finer particles of lower mass follow a trajectory along the inside of the mill. Micronized mica discharges from the mill via an outlet located on the inside diameter of the mill.

The micronized mica is collected with cyclone collectors or in dust collectors. Waste steam or hot air from the process may be recovered via heat exchangers. Product collected by cyclones can be further classified to produce products with controlled particle size distributions. Oversize from such a classification may be returned to the mill for further grinding.

Process variables are temperature, pressure and feed rate. The micronizing process is very energy intensive.

A possible substitute for fluid energy milling is high speed hammer mills operated in closed circuit with high efficiency air classifiers. Other equipment that may possibly be suitable for fine grinding mica are the wet grinding agitator type mills, developed in Switzerland.

Mica Separation Processes

Flotation

Separation of mica from other mineral constituents can be achieved by a number of methods. If the grinding process is wet, then froth flotation is the method most often used. Flotation of mica can be achieved in acidic or basic circuits, using anionic or cationic flotation reagents. If the grinding process is dry, a number of methods including flotation is possible.

Differential Screening

Depending on the difference in the flake size of the mica and the particle size of the gangue minerals, screening can often produce concentrates of coarse flake mica. Coarse screening can often greatly reduce the volume of material for subsequent treatment.

Air Separation Techniques

Air tables can be used for separating mica from gangue minerals. To be effective the ground material must first be screened into a number of closely sized fractions, so that each size fraction can be individually separated on the air table. This process takes advantage of differences in specific gravity between the low mass of a light mica flake and a "non flake" gangue mineral.

Air classifiers can accomplish the same function. Again, the ground mica must be fractionated by screening before size separation by air classification.

If after grinding, part of the mica is in a delaminated condition, then it is possible to achieve separation by air classification without prior size fractionation. In the air classification process, highly delaminated mica, because of its low mass will behave as a fine particle of low mass. This results in the delaminated mica discharging with the fine gangue minerals, from which the mica can be separated by screeninig. Any mica not delaminated will discharge with the coarse gangue particles. Further delamination may be achieved by regrinding the coarse fraction from the classifier and repeating the process (Figure 16).

The above processes are only applicable or effective in instances where there is a high proportion of delaminated mica after grinding. The degree of delamination is a function of the grinding process selected and the nature of the mica material.

It is important to establish the behaviour of the mica during grinding. Selection of crushing and grinding equipment that achieves a high degree of mica delamination is of critical importance. During process development the mica should be tested with a number of different size reduction processes to determine the optimum method.

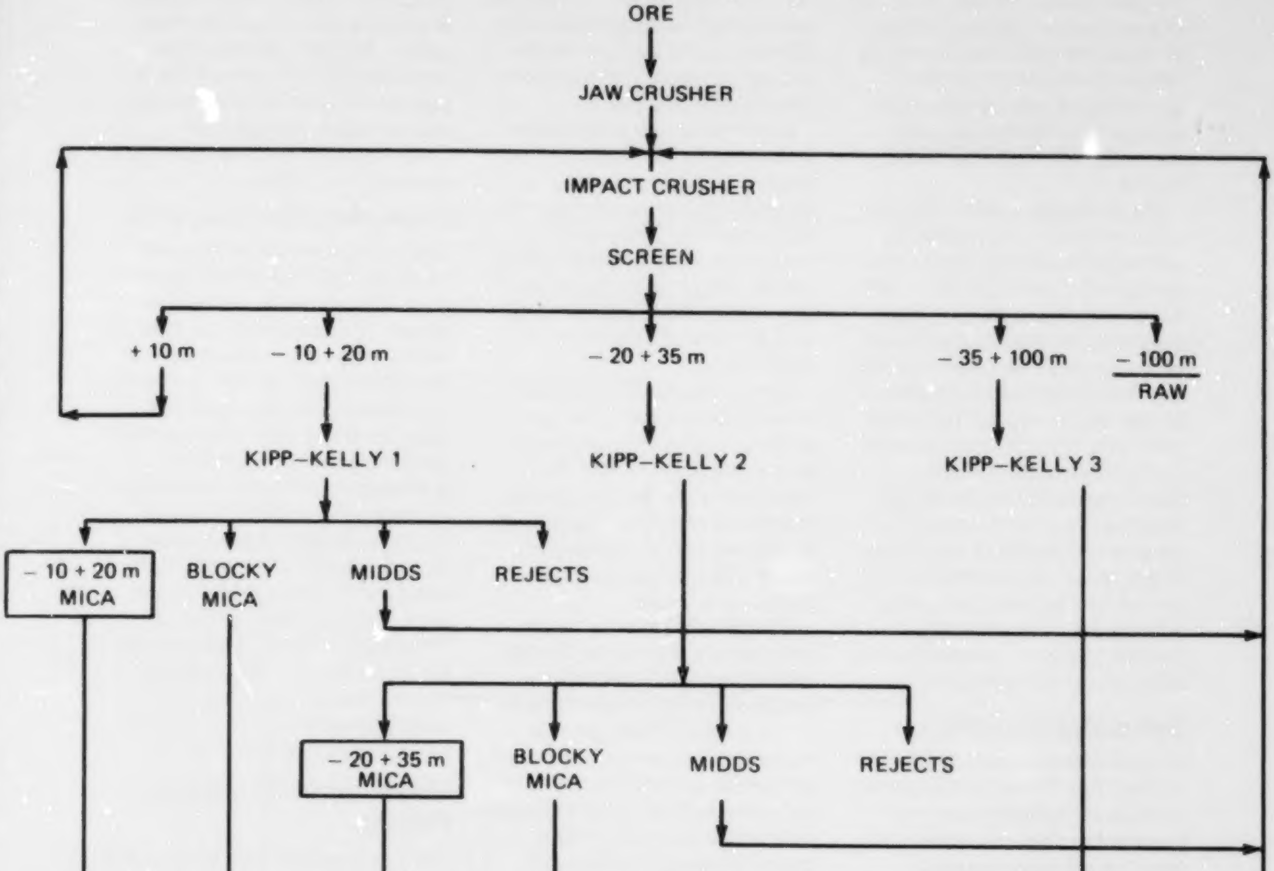
Magnetic Separation

Magnetic separation is a process that may be used to advantage in the separation of mica from gangue minerals or the separation of muscovite mica from biotite mica. The applicability of magnetic separation is dependent on the mineral constituents and their relative magnetic susceptabilities.

Other mixtures containing minerals responsive to magnetic separation may be separated using a differential separation technique. Minerals with high magnetic susceptibility would be removed first at low magnetic field strengths, followed by separation of minerals with lower

FIGURE 16

CONCEPTUAL FLOWSHEET – MICA PRODUCTION
DRY BENEFICIATION OF MICA



SOURCE : TURGEON, J. AND FOX, G.

magnetic susceptibility. In some cases concentrates consisting of muscovite mica and non magnetic minerals such as quartz and feldspar may be separated using high intensity magnetic separation at 14,000 to 20,000 Gauss.

Magnetic separation is applicable only to mineral constituents which have a distinct range of magnetic susceptibility or are mixed with those that are nonmagnetic. Muscovite micas are normally para-magnetic and will respond to magnetic separation at high field intensity. The magnetic susceptibility of muscovite is a function of its chemistry. Some muscovite micas are so pure that they will not respond to magnetic separation processes. The possibility of achieving separation by magnetic separation techniques can be ascertained through testwork, following a detailed mineralogical study.

Delamination of Mica

For applications such as plastics reinforcing, the mica must be delaminated. Delamination is a process in which mica flakes are split on the basal cleavage plane. Structurally, mica is a layered mineral, with thin flakes stacked on each other, much like a deck of playing cards. Individual flakes are very thin. The mica stacks are compressed and it is difficult to separate the flakes. Mechanical techniques have and are being developed which facilitate delamination with minimum destruction or damage to the mica flakes.

Ultrasonic techniques have also been found to be effective (Kaufman et al, 1974, p. 125-133). Other literature references (see bibliography) describe a number of delamination techniques.

The use of H.A.R. (High Aspect Ratio) mica in plastics and the processes for production of delaminated mica are considered to be in a developmental stage. Aspect ratio is the ratio of diameter of the flake to its thickness. Considerable commercial interest is shown by the plastics industry in this method of reinforcing polymers and excellent growth is forecasted.

Delamination is a technique that has been employed by the kaolin processing industry for delamination of kaolin. Special high speed agitators or extruders are used to achieve delamination. These techniques are very energy intensive but they may be applicable to mica delamination.

Wet grinding, using Chaser mills, is the old wet grinding method traditionally employed for the grinding of mica. Published literature reports that aspect ratios of 30:1 are achieved by this method. For optimum reinforcing, aspect ratios of 100:1 are required.

Effective delamination can only be achieved by processes which generate high friction forces or by the ultrasonic technique in which finely ground minerals such as silica, calcium carbonate or saturated salt solutions are used to act as the ingredients to separate the mica flakes. These processes are based on wet systems (Figure 17).

The only dry processing techniques commercially used are air tabling and dry micronizing techniques. A dry delamination and fine grinding technique is described in Turgeon and Fox (1982) and Hawley (1981).

Dry delamination has considerable cost advantages over wet delamination systems. The additional cost of solid-liquid separation by filtration and subsequent drying adds significantly to processing costs. Wet delamination produces a higher quality flake, with good lustre. Dry grinding or delamination roughens the flakes and damages the edges.

The technology for producing H.A.R. mica is advancing parallel with the increased use of H.A.R. mica as a reinforcing filler in plastics. Growth rates are considered excellent, and the utilization of mica in this application may well increase dramatically in the '80's, if additional sources of H.A.R. mica enter the market. Availability from multiple sources often results in increased acceptance by potential users (Anon., 1982).

Evaluating Mica Deposits

Evaluating new mica deposits must be undertaken with great care. The suitability of mica for industrial applications such as reinforcing filler in plastics must be established through research and development by qualified polymer chemists. Development of economically viable mica processing methods must be undertaken to establish the processing methods most suitable for a particular raw material. Development costs are likely to be significant, but are justified if "Premium Grade" products can be produced. A careful assessment of market opportunities must parallel the processing and product applications studies.

Uses, Specifications, Prices

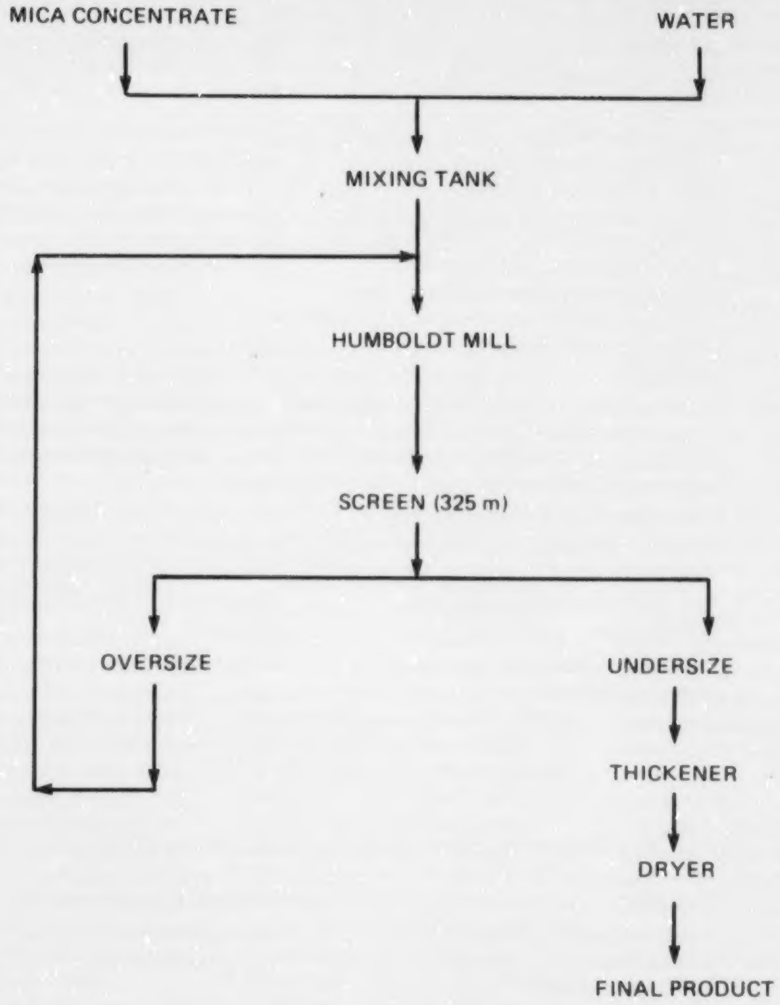
Mica as a mineral has been used for decades in a number of industrial applications. Some of these are non-filler related such as in mica paper, or in oil well drilling, where mica is used as a sealant preventing the loss of drilling fluid.

The primary fields of application in which mica is used as a filler-extender are paints, plastics, jointing compounds, roofing materials and rubber. The use of mica in concrete as a substitute for asbestos fibers is increasing.

Mica, in comparison to other mineral fillers is a relatively minor mineral. Its traditional uses with the exception of gypsum board are declining, particularly in roofing shingles and rolled roofing. Its use in paints has been stable but shows limited growth. The most dynamic growth is in plastics, as a reinforcing filler, substituting partially for higher cost fiberglass. It

FIGURE 17

CONCEPTUAL FLOWSHEET– MICA PRODUCTION
WET GRINDING OF MICA



SOURCE : TURGEON, J. AND FOX, G.

Table 25 Primary Uses for Flake Mica

Application	**Function**	**General Specifications**
Paint	Used in exterior paints, it improves film flexibility, pigment packing, prevents checking and cracking and decreases film permeability. It is also used in pipeline coatings and oil based metal primers.	Micronized or wet ground muscovite mica. 325 mesh, 30, 20 & 10 micron grades. Muscovite mica of good colour only. (i.e. white or colourless).
Plastics	As a reinforcing filler in polypropylene, polyolefins, thermoplastic polyesters, nylon A.B.S., polyurethane, it provides high tensile and flexural strength, high heat distortion, low molding shrinkage and good dimensional stability. Improved performance if it is surface coated or treated with coupling agents. Used in combination with chopped fiberglass.	Delaminated mica with aspect ratio of at least 100:1. Particle size flake:- 40, 60, 100, 200 and 325 mesh. Dry or wet ground. Amber coloured phlogopite mica is used extensively but neutral colour such as that of muscovite is preferred.
Gypsum Board Joint Cements	Provides good workability and trowelling. Reinforcement prevents cracking, checking, anti-shrinking. Used in dry & wet joint cement compounds.	Mica flakes, 70 to 200 mesh and finer. Mostly dry ground. Coarser, + 200 mesh, wet ground products are also used.
Roofing Products	Used as dusting or anti-blocking compound in rolled roofing or shingles. Some mica used as reinforcing agent.	Mica flakes–40 x 100 mesh for dusting applications. 20 x 200 mesh for use as filler in roofing products. Dry ground.
Dry Powder Fire Extinguishers	Aids flow of powders used in fire extinguishers. Is anti-caking.	Mica flakes 100 mesh and finer. Dry ground.
Insulation & Fire Retardation	As partial substitute for asbestos in asbestos cements.	Dry ground. Mica Flakes 100 mesh and finer.

Table 26 Secondary Non-Filler Applications for Mica

Application	**Function**	**General Specifications**
Welding Rod Coatings	Improves quality of welding slag. Retards bubbling and improves metal transfer across arc.	Muscovite mica 40 to 70 mesh in size. Dry ground mica.
Oil Well Drilling	As ingredient in drilling mud it acts as a sealer preventing loss of drilling fluids in porous strata.	Coarse flake mica 10 x 40 mesh in size. Dry ground.
Rubber	As a dusting and releasing agent in rubber manufacturing.	Dry ground. 200 mesh particle size.
Agricultural	Used experimentally as a dusting agent. Reflection from flakes is effective in repelling aphids.	Coarse flake mica 10 to 40 mesh. Wet ground.
Concrete	Flake mica is a potential substitute for asbestos in concrete.	
Mica Paper	Reconstituted mica sheet used in electrical, electronic and insulating applications as substitute for sheet mica.	High quality, coarse muscovite flake mica. Delaminated and reconstituted.
Foundry Molds	As a mold wash in nonferrous castings to improve surface quality of castings.	Finely ground mica. Dispersed in water or organic fluid.

is expected that new applications for mica will be developed as its good reinforcing properties become better known. Mica is being studied in many applications as a substitute for asbestos, in asbestos cements, brake linings, gasket materials and thermal insulation.

Paint

The use of mica as a pigment extender is traditional. Its main use was in oil-based exterior paints to prevent cracking and checking; mica improved film flexibility. With the demise of oil-based house paints, mica usage is now in flat latex-based paints where it aids in pigment packing, film reinforcement, preventing cracking and checking. It improves resistance to water and ultraviolet light. Mica is used in industrial oil-based primers to which it imparts good chemical resistance and reduction of vapour transmission.

Water ground grades are preferred. For paint extender applications wet ground mica has a better lustre and sheen. Clean pure muscovite micas with good colour are required. The traditional source was the cuttings and scrap from stampings or blocking of sheet mica. Several wet ground mica producers have closed their plants in the last five to ten years, largely because of poor availability of high quality scrap muscovite mica.

Loadings in paints vary from as low as 2 percent to as high as 20 percent by weight, depending on paint type and the properties desired.

The use of wet ground mica has declined and is expected to continue to decrease unless new sources of high quality muscovite become available and the efficiency of the traditional wet grinding process can be improved.

Dry ground micas are used in paint applications, where the desirable properties of wet ground mica are not essential.

Prices

In contrast to most other mineral fillers, the price structure of mica fillers is not based on particle size. Normally, fine fillers are considerably more expensive than coarser grades, but mica fillers have a rather narrow price differential. Wet ground 325 mesh mica, ranges upward from U.S. $420 per tonne in 22.7 kg (50 lb) multi wall paper bags, f.o.b. producer. The 100 mesh and 160 mesh grades are priced identical to the 325 mesh grade.

Plastics

The use of mica as a reinforcing filler in plastics is a relatively new development of the past decade. Its use has resulted from research work conducted with other flake-shaped materials such as flake glass, flake aluminum and aluminum diboride.

The reinforcing properties of flake materials are well known and documented (Adams 1965; Suffrendi 1961). Canadian researchers have been in the forefront of the development of mica as a reinforcing filler (Maine 1972). The use of delaminated mica with high aspect ratio (H.A.R.) as a reinforcing filler was first described by Lusis, Woodhams and Xanthos (1973). Professor R.T. Woodhams of the University of Toronto has pioneered the development of mica reinforced plastics and was awarded Canadian patent 893,163 in 1972 and U.S. patent 3,764,456 in 1973.

Research & development on the use of mica as a reinforcing filler has continued at a brisk pace. Numerous articles and papers have been published on the reinforcing properties and applications of high aspect ratio mica in plastics.

The commercial development and production of high aspect ratio mica products has been spearheaded by Martin Marietta International Ltd., a joint venture of Societé Minéralurgique Laviolette Inc. of Montreal and Martin Marietta Resource International Ltd. of Hunt Valley, Maryland. This company operates a mica processing plant at Boucherville, near Montreal, treating a phlogopite mica to which they give the trade name "Suzorite." The company has conducted extensive research in the development of suitable processing methods and on the use of mica as a reinforcing filler.

Commercial utilization of H.A.R. mica as a reinforcing filler is expanding and is expected to have an excellent growth rate. Its current use, compared to other mineral fillers is modest, but expectations are that it will experience the most rapid growth of any mineral filler in use today. The United States and Japan are leading with development of commercial uses.

The reinforcing properties of mica are comparable to the reinforcing properties obtained with glass fibers, but mica offers a significant cost advantage. Optimum reinforcing properties are obtained with delaminated high aspect ratio mica i.e. mica with a mean particle diameter to thickness ratio of about 100:1 (Woodhams 1978).

As with many other mineral fillers, surface treatment of mica with chlorinated paraffins, metal stearates or coupling agents, enhances their performance considerably. The type of surface treatment that is most effective may vary for different micas and polymer systems and the processes used in forming the plastic products.

High aspect ratio micas are used effectively in many polymer systems, either as the prime reinforcing filler or in combination with other reinforcing fillers such as glass fibres to achieve optimum reinforcement.

Reinforcement may vary with different polymer systems, type of surface treatment and the aspect ratio of the mica. In general the use of mica results in significant improvement of the following physical properties compared to the unfilled resin:

1. High tensile strength.
2. Higher flexural strength.
3. Higher heat deflection temperature.
4. Good molding characteristics.
5. Low warpage and high dimensional stability.
6. Low thermal expansion.
7. Low mold shrinkage.
8. Low conductivity.
9. Improved electrical properties.
10. Good resistance to weathering and attack by acids or alkalis.
11. Reduced flammability.
12. Low permeability.

The impact strength of plastics reinforced with mica is adversely affected, but surface treatment or coupling agents may minimize it.

High aspect ratio mica is used to reinforce thermo plastics and thermosets. The degree of reinforcement may vary from one polymer system to another and the type of resins used.

Special compounding techniques are required to minimize damage to the mica flakes and to obtain optimum alignment of them. Breakdown of the flakes will impair their reinforcing properties.

In comparison to fibrous reinforcements mica is simpler to process, particularly at high loadings. Typical loadings range from 20 to 50 percent but may be as high as 75 percent.

Mica is one of the few mineral fillers used in plastics that does not need to be finely ground. Particle shape, and in particular aspect ratio, is the governing factor responsible for mica's excellent reinforcing properties. Grades from 60 mesh to 325 mesh are used but 60 and 200 mesh products are most common.

The mica must be pure and free of abrasive components as these cause wear on processing equipment. The flake aspect ratio (ratio of mean diameter to thickness) should be in the range of 50:1 to 150:1. The colour should be as neutral as possible; typically silver-white for muscovite and golden-amber for phlogopite. Inclusions of other minerals may affect the flexibility of the mica flakes and cause breakdown of the flakes during processing, reducing the aspect ratio and diminishing their reinforcing properties.

Prices
Mica grades suitable for plastics reinforcing are quoted by suppliers at U.S. $210 to $345 per tonne in 22.7 kg. (50 lb) paper bags on wooden pallets in truckload quantities. Surface treated grades are offered at prices ranging from U.S. $540 to $625 per tonne in paper bags, on wooden pallets in truckload quantities. Quantities of less than a truckload are quoted at U.S. $22 per tonne higher.

Rubber

The use of mica in rubber has traditionally been as a mold release compound in rubber molding. As such it facilitates quick release of the rubber part of the mold. Mica is also used to dust freshly produced rubber so the rubber parts will not stick to each other.

Mica competes with talc in this application. The final choice is usually determined by performance and cost.

Coarse flake mica is used in this application. Particle size is approximately 20 mesh by 100 mesh or 40 mesh by 100 mesh, wet or dry ground. Mica must be pure and free of abrasive grit.

Price
Mica products used in rubber are priced in the range U.S. $140 to $200 per tonne, shipped in 22.7 kg (50 lb.) multi wall paper bags f.o.b. producers plant.

Due to its low volume, this product may be handled through local or regional distributors rather than direct purchase from the producers.

Roofing Products

Flake mica is used as an anti-sticking compound in the manufacture of rolled roofing or shingles. The mica is dusted on the asphaltic roofing to prevent sticking of the surfaces. A minor amount is used as a filler in asphaltics.

Mica competes with coarse flake talc in this application. Selection is based on performance and cost of the materials.

Dry ground flake mica is used in this application. Colour is not critical. Product size is 20 mesh by 200 mesh or 40 mesh by 100 mesh.

Price
Mica products used by the asphaltic roofing industry are sold in the range U.S. $140 to $200 per tonne shipped in 22.7 kg (50 lb.) multi wall paper bags f.o.b. producer.

The low volume of mica used in this application suggests that the products are purchased through local distributors rather than directly from the producer.

Gypsum Board Joint Cements

Mica is used extensively in the manufacturing of dry wall jointing compounds, used as crack sealers in gypsum board dry wall construction.

Mica provides good reinforcement, prevents cracking, has good slip and improves troweling properties for compounds applied with troweling knives. Mica has good dispersion properties.

Mica competes with talc, kaolin and asbestos in this application. Good brightness is desirable; dark coloured muscovite or phlogopite can be used but to a lesser extent. Dry colour is important; it should match the colour of the gypsum wall board. 100 or 200 mesh dry ground mica is used.

Price
This is one of the largest applications for flake muscovite mica.

Consumers usually purchase in bulk rather than bags. Prices quoted for dry ground mica suitable for this application range from U.S. $150 to $215 per tonne in bulk and U.S. $170 to $235 in 22.7 kg. (50 lb) multi wall paper bags, f.o.b. producer.

Oil Well Drilling Muds

Mica is an additive to oil well drilling muds in which it functions as a sealer of porous strata, preventing loss of drilling fluid by seepage.

Coarse flake mica with a particle size distribution ranging from 10 to 40 mesh is used in this application. The mica is added to the drilling fluid, the loading level depending on the porosity of the structures being drilled. Well drilling fluids are expensive and it is important to prevent losses.

Prices

Coarse flake muscovite and phlogopite micas used in oil well drilling muds are quoted at U.S. $125 to $145 per tonne shipped in truckloads, f.o.b. producers plant in 22.7 kg (50 lb) multi wall paper bags.

Most of the mica used in this application is purchased through distributors in areas where there is high well drilling activity.

Mica Paper

High quality delaminated muscovite or phlogopite mica is used for the manufacture of reconstructed sheet mica, used in the electrical and electronic industries.

Scrap mica from the production of natural mica sheets and stampings is delaminated by heating the mica, quenching it in cold water, followed by wet grinding in modified hammer mills. The ground slurry is subjected to high intensity magnetic separation to remove iron bearing and other magnetic minerals. The mica slurry is fed to a paper-making machine that provides a continuous sheet of mica.

Producers of mica paper purchase mica from various sources, and process the mica according to their requirements.

Each source of mica needs to be evaluated for its suitability in this application. No specific quality criteria are specified other than that high purity and good flake geometry are important.

Welding Rod Coatings

Mica flakes are used as an additive in welding rod coatings. Mica is used to prevent bubbling of the metal and to promote metal transfer across the arc during welding.

High quality muscovite or phlogopite mica is used in this application. Good purity is essential. Dry ground products ground to 70 mesh but containing a minimum of minus 325 mesh are commonly used.

Prices

Mica products suitable for welding rod coatings are quoted at U.S. $220 per tonne shipped in truckloads in 22.7 kg (50 lb) multi-wall paper bags f.o.b. producers plant.

Fire Extinguishers

Dry ground mica is an ingredient in dry powder fire extinguishers. Mica in this application acts as a flow promoter and anti-caking agent.

High quality dry ground muscovite or phlogopite mica is used in this application. Particle size must be controlled to provide free-flow and anti-caking characteristics. Products, essentially 100 mesh by 325 mesh, are used.

Prices

Mica products used in this application are quoted at U.S. $230 per tonne, truckload quantity packed in 22.7 kg (50 lb) multiwall paper bags.

Production

The United States is the leading producer of ground mica, accounting for about half of the world's total. In 1981 some 16 grinding plants were operated by 15 companies in 7 states, producing 120,630 tonnes of flake mica of which 106,120 tonnes were processed into ground mica with a value of U.S. $16,373,000. Most of this was a by-product of kaolin, feldspar and lithium (spodumene) mining. North Carolina accounted for two-thirds of total U.S. production in 1981, the rest being from sources in Connecticut, Georgia, New Mexico, Pennsylvania, South Carolina and South Dakota (Johnson 1982).

World production of ground mica in 1980 was 227,000 tonnes. In addition to the United States, the U.S.S.R., India and Korea are important producers.

Imports to the United States in 1980 were only 8,200 tonnes, originating largely from Canada, India and Brazil.

Canadian production was entirely from a single producer in Quebec, amounting to about 10,000 tonnes valued at an estimated $1,851,000 ($185.10 per tonne) in 1980 (Harben 1981, p. 20). In 1979 Canada imported 3,050 tonnes of which 2,342 tonnes was from the United States.

Production of sericite in the United States amounted to 37,000 tonnes valued at U.S. $107,000 ($2.88 per tonne) in 1979. It was used primarily in brick-making.

Mica has yet to realize significant growth in plastics, but if and when this develops it is expected to favour the study area because of the concentration of automobile manufacturing. Meanwhile, the estimated market for mica is summarized in Table 27.

Competitive Materials

Mica has few competitors in most applications. Talc, kaolin and wollastonite are sometimes used in dry wall compounds instead of mica, and talc and barite may substitute in paint. But in all these instances the substitutions are less desirable in terms

Table 27 Estimated Mica Filler Market, 1980-1985

	TOTAL CANADA AND UNITED STATES	STUDY AREA
	TONNES ANNUALLY	
Drywall compounds	60,000	28,000
Paint	17,000	7,000
Plastics and rubber	10,000	5,000
	87,000	40,000

of the properties they impart.

The prospect of a major market for mica in plastics is challenged by glass fibres and to some extent talc. However, mica is substantially less expensive than glass, and because of its unique properties (e.g. high aspect ratio) there are no alternative materials presently available that can completely replace it.

Trends

The prospects for growth in the consumption of ground mica are good. Its traditional markets, as an additive to oil well drilling fluids and as a component of drywall compounds, are expected to be strong over the long term. Its potential in plastics is enormous, and its use as a substitute for asbestos is accelerating.

While world supply and demand for oil will fluctuate in response to the availability of alternative fuels, conservation practices, and nationalistic programs, a continuing high level of exploration drilling in North America is assured. Mica flakes of relatively coarse size are effective in sealing porous rock units.

The use of mica in drywall compounds for its reinforcing function is well established. Its consumption is, however, directly related to residential and commercial construction, a market which is subject to large fluctuations but which will continue to experience long term growth.

Major growth potential exists as a filler in plastics, especially in polypropylene for automotive parts. With the North American automobile industry centered in the Northeast, Ontario deposits are well located to take advantage of this developing market.

Mica is expected to substitute increasingly for asbestos in a number of traditional asbestos markets. There is evidence that it can be used effectively in asbestos-cement applications, replacing asbestos fibres in the batch. It appears that mica products in general will not likely attract unfavourable environmental pressures, as asbestos has done in respect to alleged health hazards.

Other filler uses for mica, such as in paint, are expected to show unspectacular growth.

On the supply side, traditional by-product sources are not expected to be capable of major growth. New production will come mainly from deposits developed for mica as the primary product. Filler markets will favour mica products of high aspect ratio and neutral colour.

Mica is not an uncommon mineral, and it is likely that many attractive deposits will come to light when the demand is established. Mica schists are an obvious target for development, as in Quebec's "Suzorite" mine and Scotland's recent development of its Pitlochry schists.

Plate 1 *Extender Minerals Barite Mine, Matachewan, Ontario.*

Plate 2 *White Marl Shoreline, Dry Lake, Marlbank, Ontario.*

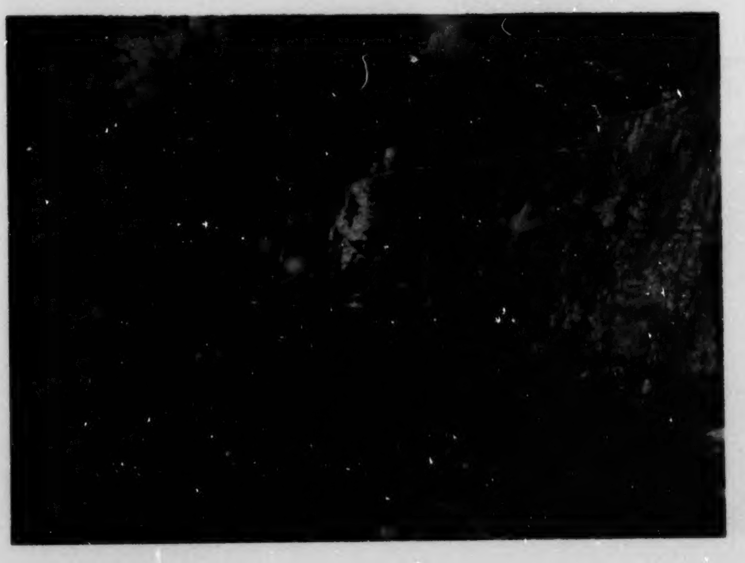


Plate 3 *Calcite Vein, Palmerston Township, Ontario*

Plate 4 *Steep Rock Calcite Quarry, Tatlock, Ontario*

Plate 5 *Steep Rock Calcium Carbonate Plant, Perth, Ontario.*

Plate 6 *White Kaolinitic Quartz Sand, Adam Creek, Moose River Basin, Ontario.*

Plate 7 *Refractory Kaolin Clay, Adam Creek, Moose River Basin, Ontario.* (Photo courtesy H.M. Verma).

Plate 8 *Koizumi Muscovite Schist deposit, Kaladar, Ontario.*

Plate 9 *W.R. Barnes Sandstone Quarry, Storrington Tp., Ontario.*

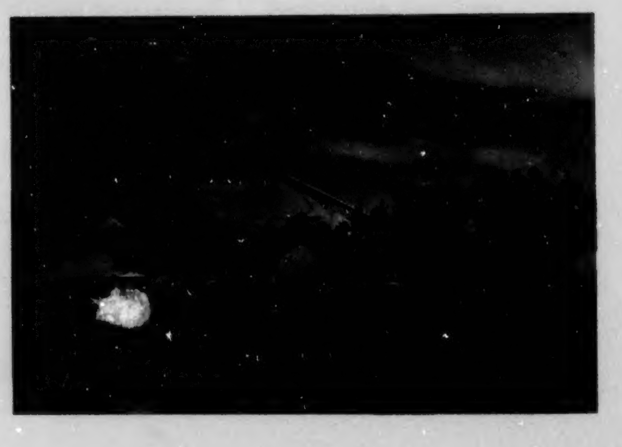


Plate 10 *Indusmin Quartzite Quarry, Badgeley Island, Ontario.*

Plate 11 *Canadian Silica Quartzite Quarry, Sheguiandah, Manitoulin Island, Ontario.*

Plate 12 *Canada Talc Plant at Madoc, Ontario.*

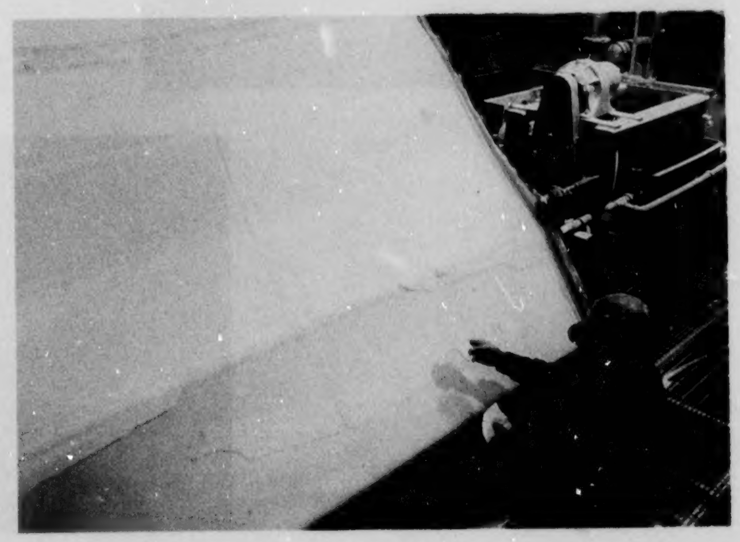


Plate 13 *Talc Concentrate Cake at Drum Filler– Steetley Talc concentrator, Penhorwood, Ontario.*

8 Silica

Summary

Silica consumption for fillers is small; paint has been its principal market, but its use in plastics is increasing rapidly. However, silica's major markets are non-fillers: glass, fiberglass, foundry sand, flux, ferrosilicon, refractory brick and artificial abrasives. Total value of silica delivered to consuming plants in Ontario in 1979 was estimated to be $31 million (Minnes 1982, p. 14). Transportation has become the major cost factor, and much of the high purity silica used in Ontario is imported from the United States.

Precambrian quartzite is quarried on Badgeley Island in northern Georgian Bay by Indusmin Limited. Lump quartzite is shipped by boat to Welland, Niagara Falls (New York) and Becancour (Quebec) for ferrosilicon production. Finer materials are further milled for glass and other uses in a plant at Midland, Ontario.

Ontario has numerous potential sources of silica in the form of sand, sandstone and quartzite, but most will require more beneficiation than existing producing properties in Ontario and the United States. Nevertheless it seems likely that new silica production in Ontario will be justified because of escalating transport costs from remote sources.

The filler market for silica is shared by synthetic as well as natural sources. Precipitated silica, pyrogenic silica, and silica gel are higher priced alternatives to natural ground silica. Precipitated silica enjoys almost as big a filler market as does natural silica, and is nearly four times as costly. Estimated market for ground silica filler is 49,000 tonnes in the study area.

Geology

Silicon dioxide, SiO_2, most commonly referred to as "silica", is the most abundant oxide in the earth's crust; it comprises about 60 percent of the average composition of the crust. Many minerals are silicates, which are chemical combinations of silica and other elements and oxides, but silica also occurs alone as the mineral quartz.

Quartz is the common mineral form of silica, but there are two other distinct crystal forms which crystallize at higher temperatures, tridymite and cristobalite, which are only rarely found in nature. Cryptocrystalline forms of silica include chalcedony and its varieties agate and onyx, flint, and chert, jasper and opal.

Quartz occurs commonly in Ontario in pegmatites and veins; it also may predominate in deposits of sand, sandstone and quartzite. In the United States, deposits of tripoli, diatomite, rottenstone and novaculite are also sources of silica. The various types of silica deposits are briefly described in the following section.

Types of Silica Deposits

Sand

Natural deposits of sand may consist predominantly of quartz, but varying proportions of feldspar, carbonate, ferromagnesian and accessory minerals are usually present. Only rarely do natural sands approach a pure silica quality which would require a minimum of beneficiation for commercial utilization.

Most Ontario sands are of glacial origin and very impure, but recent fluvial and aeolian activity may have in some cases improved them sightly. Local deposits of sand derived largely from highly-siliceous bedrocks may also be found to have higher natural purity.

Certain deposits of feldspathic sands in the United States have been successfully worked for both feldspar and silica products, and good quality silica and sand is often a by-product of kaolin processing. Nevertheless, as a group, unconsolidated sand deposits are not a major source of silica.

Sandstone

Sandstones can also vary considerably in composition, but some are of high purity and, as a group, sandstones are the most important commercial source of silica. Deposits which may be considered as sources of silica are typically composed largely of quartz grains weakly cemented by siliceous or calcareous material.

Paleozoic sandstones such as the St. Peter Formation of Illinois and Missouri, the Potsdam or Nepean of eastern Ontario and Quebec, and the Oriskany and Sylvania of Ontario and the United States are major sources of silica. They probably owe their purity and desirable rounded grain shapes to multiple stages of weathering, deposition and reworking.

Quartzite

Just as sandstone is a more or less indurated sand, quartzite is a denser form or a metamorphosed form of sandstone. The distinction is made at the stage where individual quartz grains lose their identity through recrystallization, and fracturing of the stone is no longer restricted to grain boundaries. Quartzite does not have the granular texture of sandstone, and on crushing produces typically sharp and angular fragments.

Ontario's Lorrain and Bar River quartzites of Precambrian age are important sources of silica.

Pegmatites and Veins

Pegmatite dikes and quartz veins are intrusive igneous rocks which typically contain limited amounts of quartz but which may be sources of unusually high purity silica. As with quartzites, silica from these sources is extremely abrasive on mining and processing equipment, and the resulting silica product consists of sharp and angular fragments.

While such deposits should not be overlooked for small specialty markets demanding unusually high natural chemical purity, they are not normally considered important sources of silica.

Tripoli

Tripoli is a soft, highly siliceous sedimentary rock composed of fine disintegrated chert and the microscopic siliceous shells of diatoms and radiolaria. Deposits are believed to be the result of the leaching of siliceous limestones or calcareous cherts.

Deposits of tripoli are found in Illinois, Missouri, Oklahoma and Arkansas but are not known in Ontario.

Diatomite

Diatomite, or diatomaceous earth, is a soft unconsolidated accumulation of siliceous diatom shells, commonly with impurities of sand, clay and organic material.

California is the most important commercial source. Thin peaty deposits of recent origin in the Muskoka and Parry Sound areas of southern Ontario have been commercially investigated (D.F. Hewitt 1967a,p.34-44).

Rottenstone

Rottenstone is similar to tripoli, and is a soft, light, earthy deposit of fine silica derived from the decomposition of siliceous limestone or shale. It is mined in Pennsylvania but is not known to occur in Ontario.

Novaculite

Novaculite is a fine grained siliceous sedimentary rock noted particularly from Arkansas as a source of whetstone.

Other Sources

Silica is also sometimes recovered as a by-product of feldspar mining, as in the beneficiation of "alaskite" in North Carolina. It is also produced as a by-product of kaolin mining in Georgia, South Carolina, California and Florida.

In northern Ontario, the Cretaceous kaolin-quartz sands of the Moose River Basin are an important potential source of silica.

Ontario Occurrences

In Ontario the principal sources of silica have been the Bar River and Lorrain quartzites of Precambrian age. Possible sources also include most of the occurrences listed in Table 28, which are further described on the following pages.

Surficial Sands

Surficial sands of Ontario owe their origin primarily to glacial events of the Pleistocene, and hence have compositions that reflect the bedrocks from which they were abraded. They are normally not high in quartz content, ranging between 17 to 62 percent as shown in Table 29.

Not surprisingly, higher quartz contents tend to prevail in sands derived from siliceous rocks, such as the Potsdam Sandstone areas of Kingston-Gananoque. Higher quartz levels might be expected also in the vicinity of the Precambrian quartzites along the north shore of Lake Huron.

Two surficial sand deposits which have been investigated as possible sources of silica include the Campement d'Ours deposit near Sault Ste. Marie, and the Westree sand deposit midway between Sudbury and Timmins.

Campement d'Ours

A small deposit of high-purity quartz sand occurs on the southwest shore of Campement d'Ours Island and in the channel and islands between it and St. Joseph's Island (Fig. 18). The sand was derived by weathering of the Lake Superior Sandstone over which it lies to a maximum thickness of about 2 m.

The quartz grains are generally well-rounded and sized largely between 20 and 100 mesh. The average of two analyses reported by Hewitt (1963, p.32) is given in Table 30.

Samples were tested by Domglas Inc. and Pilkington Glass Industries Limited with satisfactory results for glass sand (P.E. Giblin, personal communication). In 1958-9 the deposit was evaluated by The Rochester and Pittsburgh Coal Company; reserves of 725,000 to 1,800,000 tonnes were estimated (Hewitt 1963, p. 32).

Westree Sand

Several large outwash deposits of sand and minor gravel were tested by auger in 1982 to depths of 16 m along Highway 560 in Westbrook and Garvey Townships a short distance east of Highway 144 (Guillet 1983). The site is approximately midway between Sudbury and Timmins in northern Ontario.

The raw material is essentially a feldspathic sand. Composite auger samples screened to − 30 + 150 mesh were subjected to attrition scrubbing and dry magnetic separation, with the result that a combined feldspar–silica product suitable for fiberglass and coloured glass markets was produced (Table 30).

Further beneficiation by flotation was particulary successful on the Garvey Township deposit,

Table 28: Major Silica Occurrences in Ontario

Formation or Type of Deposit	Geological Age
Surficial sands	Pleistocene and Recent
Kaolin-quartz sands	Cretaceous
Sylvania Sandstone	Devonian
Oriskany Sandstone	Devonian
Potsdam (Nepean) Sandstone	Cambrian
Pegmatites and Veins	Late Precambrian?
Bar River Quartzite	Middle (?) Precambrian
Lorrain Quartzite	Middle (?) Precambrian

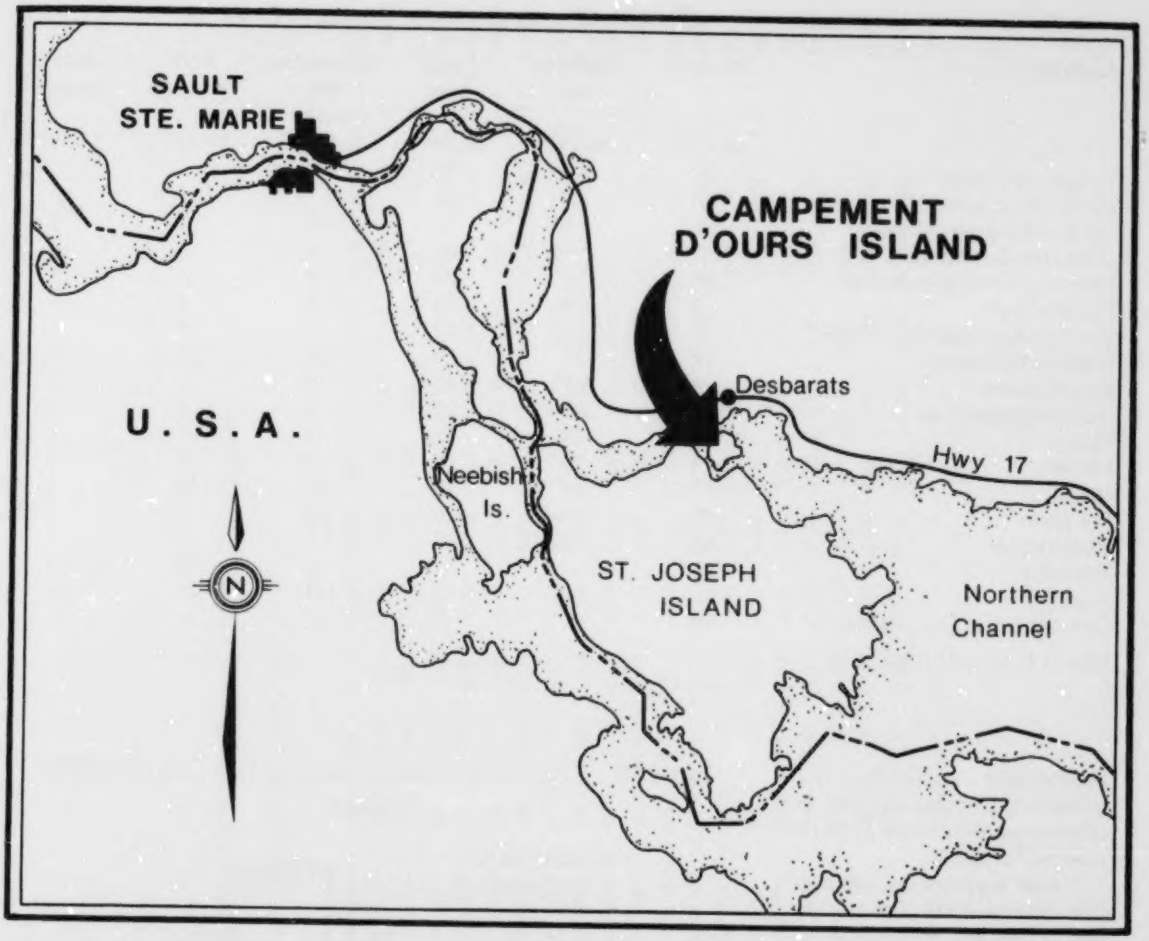


Figure 18

CAMPEMENT D'OURS SILICA SAND DEPOSIT

Scale

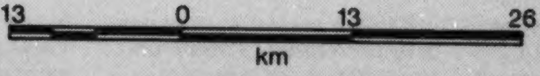


Table 29 Mineralogy of Some Surficial Sands in Ontario

Locality	**Quartz**	**Carbonate**	**Feldspar**	**Shale and Siltstone**	**Acid Igneous**	**Basic Igneous**
	percent	percent	percent	percent	percent	percent
Niagara bar sand	60	15	22	–	–	–
Picton dune sand	50	18	29	–	–	–
Sydenham area, Kingston	62	8	17	5	2	2
Dixon pit, Gananoque	54	9	25	4	4	–
Kingston Sand and Gravel	54	10	24	2	4	4
Fenelon Falls	19	38	24	14	3	–
General Aggregates, Oshawa	38	35	22	–	5	–
Niagara Falls area	42	11	20	27	1	–
Bowmanville	26	49	20	1	1	1
Pickering township	33	35	20	5	4	2
Malton	34	33	15	8	7	2
Maple	43	25	22	3	5	1
Milton	17	31	13	28	10	1
Clarkson	23	27	16	26	7	2
Picton esker	56	15	21	3	2	1
North Bay	26	–	42	–	18	11
Sudbury	29	–	17	–	21	34
Campement d'Ours Island	99	–	–	–	–	–

After D.F. Hewitt, 1963, p. 31

producing a silica product approaching flint glass quality, but at the expense of a very low recovery (Table 30).

These two products represent overall recoveries of about 51 and 17 percent respectively. Commercial production of high-purity silica product seems unlikely from such a low grade raw material.

Table 30 Chemical Compositions of Two Ontario Sand Deposits

	CAMPEMENT D'OURS	WESTREE	
	(1)	(2)	(3)
SiO_2	99.18	80.7	97.5
Al_2O_3	0.29	10.3	0.51
Fe_2O_3	0.08	0.18	0.054
CaO	0.02	2.19	0.25
MgO	0.02	0.16	0.19
Na_2O	0.05	3.47	0.09
K_2O	0.5	1.81	0.10
TiO_2	0.07	0.03	0.02

(1) Raw sand; average of two samples. Ref: D.F. Hewitt 1963, p.32.

(2) Nonmagnetic product; average of seven samples. Ref: J. Kriens, Table V, p. 1-14 (G.R. Guillet 1983).

(3) Nonmagnetic and flotation product; average of four samples. Ref: J. Kriens, Table IX, p. 1-18 (G.R. Guillet 1983).

Kaolin–Quartz Sands

Deposits of quartz sand containing a matrix of kaolin occur over a wide area in the Moose River Basin on the James Bay Lowland of northern Ontario. Cretaceous in age, they owe their preservation from severe glacial goudging to an escarpment of Precambrian rocks which effectively deflected the Pleistocene ice sheets. More restricted deposits of similar composition are also found within the resistant rim of the Cargill carbonatite 100 km to the southwest.

Kaolin is present to a greater or lesser extent to a maximum of about 20 percent in beds of almost pure subangular quartz grains. Individual sand beds vary up to 20 m in thickness, and in places exceed an aggregate thickness of 100 m interspersed with relatively thin lenses of brightly-coloured plastic clays.

The Cretaceous sediments of the Moose River Basin are

Table 31 Composition of Quartz Sands, Moose River Basin

(– 20 + 100 mesh fraction)

Hole and Sample No.	Description	Footage Analysed	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	L.O.I.	Total
78-01-9	white, kaolinitic	154-156	98.4	2.20	0.02	0.20	0.20	0.20	0.10	0.15	0.04	0.02	0.6	101.4
-11	grey; grains angular to round	286-290	97.9	1.80	0.03	0.20	0.20	0.20	0.28	0.03	0.04	0.02	0.5	100.3
78-02-25	kaolinitic; grains angular	421-423	96.2	1.30	0.02	0.20	0.20	0.20	0.10	0.04	0.04	0.02	0.5	98.1
-36	kaolinitic; iron stained, angular	474-476	97.5	1.50	0.03	0.20	0.20	0.20	0.10	0.04	0.04	0.02	0.2	99.3
-38	kaolinitic; coarse grained, angular	494-496	96.5	2.40	0.03	0.20	0.20	0.20	0.10	0.07	0.04	0.02	0.4	99.4
-44	kaolinitic; med-coarse grained, angular	540-544	98.1	1.60	0.04	0.20	0.20	0.20	0.10	0.06	0.04	0.02	0.3	100.1
78-03- 3	trace kaolinite; fine grained, angular	205-214	97.0	1.60	0.02	0.20	0.20	0.20	0.10	0.03	0.04	0.02	0.4	99.1
- 6	trace kaolinite, angular, iron stained	234-240	99.1	1.40	0.02	0.20	0.20	0.20	0.10	0.02	0.04	0.02	0.3	100.8
-10	minor kaolinite, light grey, silty	275-277	97.0	2.10	0.18	0.20	0.20	0.20	0.10	0.13	0.04	0.02	0.6	100.0
-12	coarse grained; minor mica, kaolinite	296-298	97.4	1.90	0.14	0.20	0.20	0.20	0.10	0.04	0.04	0.02	0.4	99.9
-33	silty; minor kaolinite	444-446	98.0	1.70	0.03	0.20	0.20	0.20	0.10	0.02	0.04	0.02	0.3	100.1
-39	fine grained, angular, kaolinitic	500-502	97.4	1.50	0.05	0.20	0.20	0.20	0.10	0.03	0.04	0.02	0.4	99.4
78-04- 6	trace kaolinite; occasional mica	338-343	98.3	1.90	0.13	0.20	0.20	0.20	0.10	0.03	0.04	0.02	0.5	100.8
-16	angular; silty clay interbeds	420-424	98.4	1.40	0.03	0.20	0.20	0.20	0.10	0.02	0.04	0.02	0.3	100.1
78-06-16	kaolinitic; limonite, dark grey fragments	153-158	97.0	1.80	0.22	0.20	0.20	0.20	0.10	0.10	0.04	0.02	0.7	99.8
-21	kaolinitic, angular; lignite	200-202	97.6	1.80	0.07	0.20	0.20	0.20	0.10	0.05	0.04	0.02	0.4	99.9
-26	kaolinitic; grains round	249-251	97.0	2.00	0.04	0.20	0.20	0.20	0.10	0.07	0.04	0.02	0.4	99.5
-28	minor kaolinite; fine grained, angular	269-271	96.5	1.90	0.03	0.20	0.20	0.20	0.10	0.06	0.04	0.02	0.5	99.0
78-08- 1	kaolinitic; fine grained, angular	135-140	98.0	1.40	0.05	0.20	0.20	0.20	0.10	0.05	0.04	0.02	0.3	99.8

Analyses by Geoscience Laboratories, Ontario Geological Survey
From M.A. Vos 1982

known to occur over an east-west width of 80 km marginal to the Precambrian Shield. They gradually thin northward and are lost within about 40 km. Outcrops are confined to a few river bank exposures, the rest being covered by a thick overburden of glacial till and muskeg. The geology is more fully described in the section on Kaolin.

The quartz sand is easily washed free of kaolin, and in most places the resulting sand consists predominantly of quartz with minor impurities. M.A. Vos (1981, p. 19-35) gives detailed descriptions of sand samples from various elevations in a number of deep drillholes. Chemical compositions of a number of sand samples from drillholes across the Cretaceous Basin are reproduced in Table 31 (Vos, 1982). To eliminate some coarse dark minerals and rock fragments, and to remove some of the kaolinite, only the minus 20 plus 100 mesh fractions were analyzed, the size range of most interest for glassmaking. In general the sand is coarse and angular as demonstrated by Table 32 which gives the total grain size distribution for the same samples.

Moose River sand and kaolin deposits have received a surprising amount of exploration interest over the past 50 or 60 years, considering their remoteness and difficult physical environment. However, it is generally believed that the key to their development depends on economic utilization of the kaolin resources, to which the quartz sands might become a useful by-product.

Sylvania Sandstone

A well-sorted, medium grained quartz sandstone occurs at a shallow depth in Malden Township, south of Amherstburg, in southwestern Ontario. It is quarried at Rockwood, Michigan, for glass and foundry purposes.

The Sylvania Sandstone of Middle Devonian age comprises two beds, each about 8 m thick, separated by less than 1 m of sandy dolomite. These two sandstone layers are overlain and underlain by dolomite to which they are gradational.

The sandstone is grey to white in colour, reflecting varying amounts of dolomitic cement. Sand grains are well rounded. The sandstone units are friable and sugary textured. Where they are purest they may be unconsolidated for lack of dolomite cement.

Sylvania Sandstone outcrops in the bed of the Detroit River, where it is dredged periodically to maintain the Amherstburg Channel for shipping. It does not outcrop in Ontario, but is closest to surface in lot 5, concession I, Malden Township, opposite the south end of Bois Blanc Island (Fig. 19). Here it was tested by a vertical shaft and four drillholes in 1926-7 (Dyer 1930, p. 41-46)

Table 32 Sieve Analyses of Quartz Sands, Moose River Basin

Hole and Sample No.	Oversize (weight)	Wt. Used	Size Fractions (weight percent)										
			– 10 + 14	– 14 + 18	– 18 + 25	– 25 + 35	– 35 + 45	– 45 + 60	– 60 + 80	– 80 + 120	– 120 + 170	– 170 + 230	– 230 + Dust
78-01- 9	8.6	100	3.1	5.6	8.4	23.0	25.3	19.0	9.6	2.8	1.0	.5	1.7
11	.2	100	1.7	9.0	15.6	26.5	24.3	13.2	5.1	2.1	.9	.4	1.2
78-02-25	1.3	100	2.7	4.8	8.2	15.0	16.3	17.2	14.1	7.9	5.1	3.0	5.7
36	11.9	100	20.3	32.8	23.7	12.9	5.2	2.7	1.1	.4	.2	.1	.6
38	11.3	100	5.5	7.1	9.9	18.0	23.7	25.9	8.1	.7	.2	.1	.8
44	14.5	100	14.1	14.7	18.4	26.6	12.6	6.8	3.4	1.5	.6	.3	1.2
78-03- 3	4.0	100	6.3	13.5	23.2	31.8	14.7	6.2	2.3	.6	.3	.1	1.0
6	7.5	100	13.8	21.7	25.1	22.9	10.1	3.6	1.0	.3	.2	.1	1.2
10	6.7	100	15.2	27.8	25.7	20.2	6.5	2.1	.8	.3	.2	.1	1.1
12	40.7	100	48.5	33.3	13.9	3.7	.5	.1	–	–	–	–	–
33	9.7	100	12.5	21.1	19.9	24.2	14.2	4.2	1.5	.7	.4	.3	1.0
39	0.1	100	1.1	3.5	6.8	11.7	13.5	16.2	15.2	10.4	7.6	5.2	8.8
78-04- 6	4.5	100	9.8	17.2	21.3	25.8	14.8	6.7	2.5	.6	.2	–	1.1
16	2.1	100	5.1	13.5	24.4	32.4	16.1	5.7	1.6	.4	.1	–	.8
78-06-16	–	100	.1	.3	1.1	12.6	44.7	28.9	6.2	2.1	1.0	.6	2.4
21	21.6	100	44.0	22.4	13.2	10.0	5.4	2.9	1.0	.4	.1	.1	.5
26	3.2	100	4.0	7.3	14.1	26.3	22.8	11.5	5.9	2.8	1.6	.9	2.8
28	2.8	100	3.9	7.8	14.7	29.8	27.3	11.1	2.9	1.0	.5	.2	.8
78-08-01	1.3	100	1.4	2.5	5.5	17.4	34.6	28.3	7.0	1.5	.6	.2	1.0

Analyses by Geoscience Laboratories, Ontario Geological Survey
From M.A. Vos 1982.

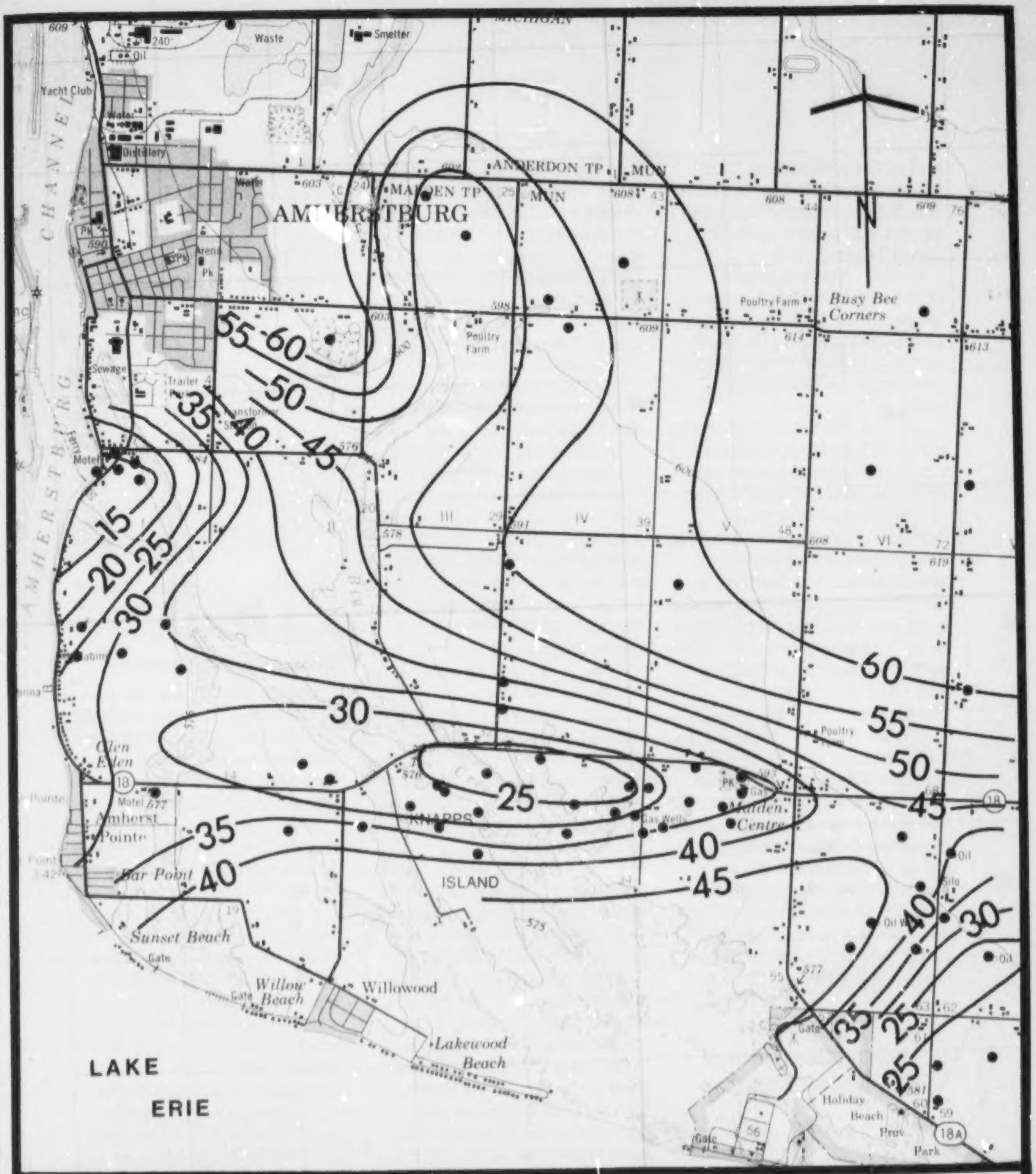


Figure 19

THE SYLVANIA SANDSTONE IN SOUTHWESTERN ONTARIO

Scale 1:50,000

0 1 km 2 3

Legend

●	Exploratory Drillhole, Gas Or Oil Well
15	Depth To Top Of Sandstone (metres)

and by five drillholes in 1959 (Reavely and Winder 1959, p.3). Top of the sandstone was intersected at depths ranging between 9 m and 16 m.

In 1961, four holes were drilled in the Malden gas field 6 km southeast of Amherstburg, encountering 25 m to 30 m of combined glacial till and dolomitic overburden (Hewitt 1963, p.29).

In 1982, five holes were drilled in lots 10 and 11, concession I, where the combined thickness of till and dolomite overburden ranged from 22 m to 36 m.

A hole drilled in the floor of the Amherst Quarry in lot 22, concession II, intersected the top of the sandstone at 26 m; the quarry was estimated to be 40 m deep. The sandstone was intersected in the shaft of the Ojibway salt mine just south of Windsor, at 110 m.

The sandstone is readily amenable to beneficiation by attrition scrubbing and flotation, which effectively lowers the carbonate and iron contents to levels acceptable for glass-making. A typical analysis of the raw sandstone as reported by Dyer (1930, p.41-46) is shown in Table 33. Natural grain size is about 92 percent between 28 and 100 mesh (Hewitt 1963, p.29).

Table 33
Typical Composition of Sylvania Sandstone

	Percent
SiO_2	93.46
Fe_2O_3	0.46
Al_2O_3	1.09
CaO	1.84
MgO	0.67
Ignition loss	2.36
	99.88

Oriskany Sandstone

The only exposure of Oriskany Sandstone in Ontario outcrops in an area of several square kilometres in the former Oneida and North Cayuga townships, now the Town of Haldimand. The occurrence was the subject of much environmental concern in public hearings that preceded the opening of the Oneida crushed aggregate quarry in 1979. Although that quarry uses only the underlying Bertie-Akron Dolomite, it stockpiles the sandstone that is stripped from the quarry area.

Typically a thickness of 1 to 3 m of sandstone is available in the immediate area of the Oneida Quarry, but as much as 6 m may be available elsewhere. The stone is buff to grey, medium-grained, thin to thick bedded, and in places rusty stained. Because of a variable content of calcium and magnesium carbonates up to about 6 percent, acting as a natural cement for the subrounded quartz grains, the stone varies from compact to friable.

A number of small quarries have been opened in the sandstone from time to time (Figure 20) and in 1962 two quarries were operated intermittently by William R. Barnes Company and by Cayuga Quarries Limited (Hewitt 1963, p.27). Until 1981 the Barnes company continued to ship small amounts of the sandstone for use in the manufacture of rock wool insulation.

The most active period of development was 1912-1918 when Oneida Lime Company, Pilkington Brothers, and Consolidated Plate Glass Company held portions of the sandstone lands. Oneida Lime Company produced glass sand and foundry sand during this period from a quarry in the south part of lot 49, concession I, Oneida Township. Pilkington Brothers also produced a small amount of glass sand from a nearby quarry in lot 48.

Although the iron and lime contents are too high in the crude sandstone, laboratory studies involving attrition scrubbing and flotation encourage the possibility of reducing these to acceptable levels for glass-making. Typical composition of the crude sandstone is given in Table 34 (Hewitt 1963, p.28).

Table 34
Typical Composition of Oriskany Sandstone

	Percent
SiO_2	91.28
Al_2O_3	1.37
Fe_2O_3	0.06
MgO	0.09
CaO	2.85
Na_2O	0.05
K_2O	0.07
TiO_2	0.04
L.O.I.	2.94
	98.75

Analysis by Laboratory Branch, Ontario Department of Mines. From D.F. Hewitt 1963, p.28.

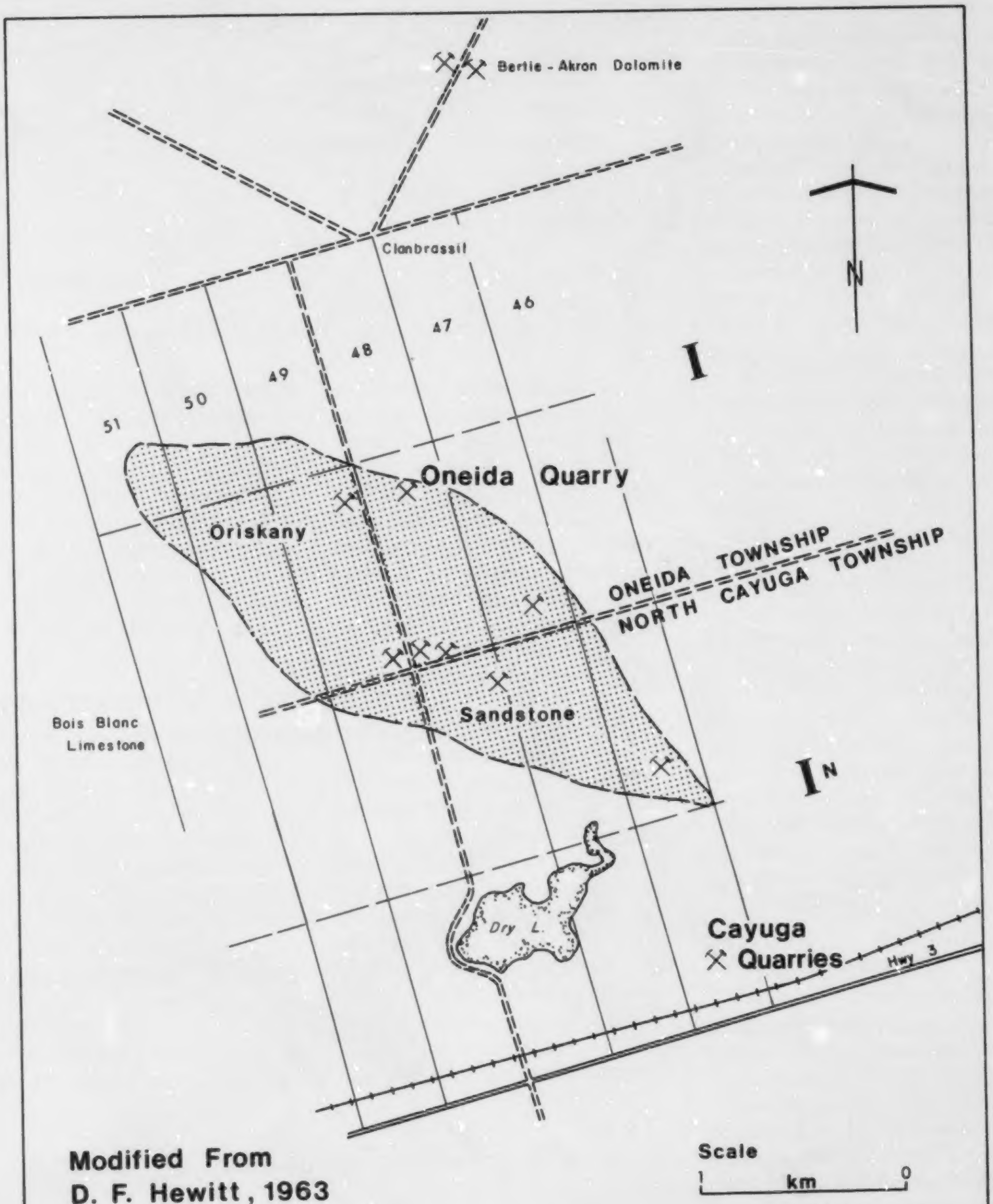
Potsdam Sandstone

Potsdam Sandstone is exposed in numerous places in the area between Kingston, Brockville and Perth in southeastern Ontario (Figure 21). It forms the bottom of the Paleozoic sequence in Ontario, and is believed to be Cambrian in age. It rests unconformably on the eroded Precambrian surface.

Potsdam Sandstone is a rather hard, well-indurated sandstone, varying in colour from white through pale shades of grey, buff and red depending on whether the cementing matrix is predominantly siliceous, calcareous or ferruginous. It consists principally of subrounded to angular quartz grains sized between 28 and 100 mesh. Both near shore and deep water facies are recognized, and in most cases the purest sandstone is the near shore variety.

Potsdam Sandstone is quarried for glass-making at St. Canut north of Montreal, but attempts at commercial production in Ontario have been short-lived. The record of exploration activity in Ontario to 1961 is described by D.F. Hewitt (1963, p.17-25).

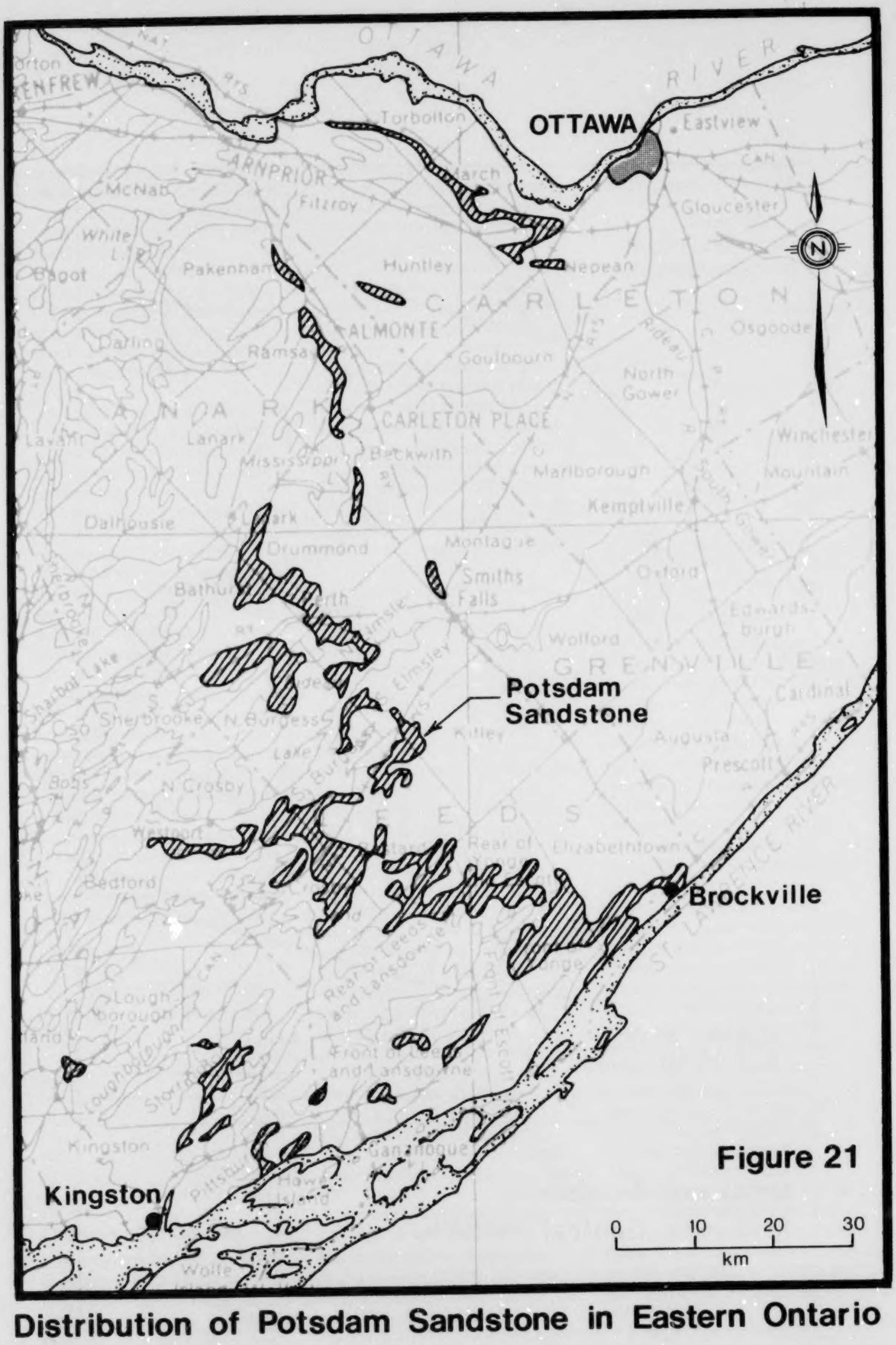
In recent years there has been much further interest in Potsdam



Modified From
D. F. Hewitt, 1963

Figure 20

Oriskany Sandstone
In South-Central Ontario



Distribution of Potsdam Sandstone in Eastern Ontario

Table 35 Typical Composition of Potsdam Sandstone

	Raw Sandstone Percent	Flotation Product Percent
Fe_2O_3	0.26	0.031
Al_2O_3	1.00	0.18
CaO	2.48	0.07
MgO	.26	0.02
K_2O	.28	
SiO_2 (by difference)	95.72	99.70
	100.00	100.00

Source: IMD Laboratories Ltd., personal communication.

Sandstone as a domestic source of silica for Ontario's glass industry. It is recognized that beneficiation by flotation, and possibly magnetic separation, will be necessary to make a silica product of high purity. Typical composition of the sandstone before and after flotation is given in Table 35.

Pegmatites and Veins

Granite pegmatites are numerous in Ontario. Some may be potential sources of very high purity silica, but only minor amounts have ever been produced. Of 616 deposits which have been worked to a greater or less extent, none were operated exclusively for quartz. Feldspar, uranium and rare earth minerals were the principal minerals sought (Table 36).

Pegmatites are normally either zoned or unzoned and are lenticular or pod-shaped. In zoned pegmatites, massive segregations of quartz may occupy the core zone. Zoned pegmatites were particularly sought by early feldspar producers, because the massively crystallized feldspar, which like quartz was also distinctly segregated, could be easily mined and shipped without beneficiation. The quartz was usually left untouched.

Quartz-feldspar pegmatites are particularly common in the Grenville rocks of southern Ontario. They tend to be grouped geographically in the vicinity of Verona, Perth, Bancroft, Madawaska, Parry Sound, Sudbury and Mattawa (Hewitt 1967b,p.11).

Peak feldspar production in Ontario was in 1920, and there has been little production since 1954 (Hewitt 1967b,p.12-13) partly due to competition from nepheline syenite. However, there is a continuing market for high potash feldspar, and some Ontario pegmatites are probably large enough and of suitable quality.

Table 36 Pegmatite Deposits Opened in Ontario

Major Commodity Sought	Number of Deposits Opened
Feldspar	197
Rare earth minerals	128
Uranium	105
Muscovite mica	63
Lithium	46
Molybdenum	34
Beryllium	23
Nepheline	9
Columbite	8
Tin	3
	616

Source: D.F. Hewitt 1967b,p.1

Even unzoned pegmatites, which have largely been disregarded in the past, might be suitable with flotation. In either case a quartz by-product would be logical.

Less common are deposits of vein quartz of mineable size. A few have been worked in recent years to provide crushed decorative chips. Among others, veins of limited size have been worked near Dorset and north of Sudbury.

The quartz in pegmatites and veins is commonly milky white in colour, but may be clear, pink or smoky. Although very limited in extent, clear colourless pegmatitic quartz has been sought in recent years for use in electronics, fiber optics and photovoltaic cells for solar energy. Extremely high purity is essential for this small but high-priced market. A deposit at Madawaska was investigated in 1980-81 but found to be too limited in extent.

Bar River Quartzite

Three quartzite formations are distinguished at the top of the Cobalt Group in the Huronian Supergroup of Middle to Late Precambrian age. They form a conformable series in which the purest is the Bar River Formation at the top of the series, underlain successively by the Gordon Lake and Lorrain formations.

The Bar River Formation is at least 900 m thick comprising five intergradational units consisting mainly of "....rounded, well-sorted, fine to medium (0.1 to 0.3 mm diameter) grains of quartz (95%) with recrystallized silica cement and minor amounts of muscovite and accessory hematite, zircon, tourmaline, and monazite" (Card 1975, p. 166).

The Bar River Formation is well exposed on a chain of islands in the North Channel of Georgian Bay (Lake Huron), including from east to west: Pine Island north of Killarney, Badgeley Island, Centre, Partridge and Heywood Islands, and at Sheguiandah on Manitoulin Island (Card 1976, Map 2318).

Bar River Quartzite is quarried by Indusmin Limited on Badgeley Island, primarily for ferrosilicon and glass sand. It was formerly quarried also at Sheguiandah on Manitoulin Island. Typical compositions of the quartzite at both locations are shown in Table 37. Other locations are described by Vos (1981, p. 4-19).

Lorrain Quartzite

Lorrain Quartzite is the lower formation of the three upper siliceous units of the Cobalt Group. It is overlain by the Gordon Lake and Bar River Formations, and is underlain by conglomerates and greywackes of the Gowganda Formation. While the Gordon Lake Formation consists of impure quartzite and micaceous gneisses, the Lorrain in many places approaches the purity of the Bar River Quartzite but with a significantly higher alumina content.

Lorrain Quartzite is exposed in many places along the north shore of Lake Huron between Sault Ste. Marie and Killarney. It is described by D.F. Hewitt (1963, p.7) as occurring in four belts readily accessible to road, rail and water transport. However, Hewitt refers mainly to the upper high purity section of the Lorrain which has since been designated Bar River Formation.

A number of early quarry operations are mentioned by Hewitt (1963, p. 7-14), some of which were undoubtedly in what we now know as Bar River Quartzite. The Bellevue quarry north of Sault Ste. Marie formerly supplied quartzite for the making of silica brick. The Lawson quarry at Whitefish Falls provided silica flux for Sudbury nickel smelters. The Killarney quarry produced lump quartzite for ferrosilicon. The Sheguiandah quarry south of Little Current, Manitoulin Island, also provided lump quartzite for ferrosilicon.

Table 37 Typical Compositions of Precambrian Quartzites

	BAR RIVER FORMATION		LORRAIN FORMATION	GRENVILLE QUARTZITE
	(1)	(2)	(3)	(4)
	Badgeley Is.	Sheguiandah	McGregor Pt.	Alban
SiO_2	98.50	97.9	94.1	96.9
Al_2O_3	0.80	0.80	3.46	0.68
Fe_2O_3	0.04	0.08	0.02	0.22
MgO	0.03	0.07	0.13	0.03
CaO		0.04	0.01	0.00
Na_2O	0.01	0.10	0.13	0.01
K_2O	0.14	0.30	0.38	0.09
L.O.I.	0.16	0.24	0.43	0.12
TiO_2	0.02	0.05	0.06	0.06
P_2O_5	0.01	0.03	0.01	0.01
MnO		0.01	0.00	0.00
	99.7	99.6	98.7	98.1

Sources: (1) A.R. Watt 1974.
(2) M.A. Vos 1981, p.9 (Average of 3 samples).
(3) M.A. Vos 1981, p.13 (Average of samples 1 to 4 incl.)
(4) M.A. Vos 1981, p.18 (Average of samples 3 and 6).

Rocks similar to Bar River and Lorrain occur in Grenville terrain at Alban on the French River.

Producers

Canadian Producers

Nova Scotia Sand and Gravel Limited

High purity silica is produced from Cretaceous quartz sands at Elmsvale and Brazil Lake in central Nova Scotia by Nova Scotia Sand & Gravel Limited. The sand deposits consist predominantly of angular quartz grains with minor amounts of kaolinite, feldspar and muscovite. Associated with the sands are lenticular beds of variously coloured plastic clays, some of which are refractory. The silica is marketed primarily as sand for glass, fibreglass and other industrial purposes.

Indusmin Limited, St. Canut, Quebec

Sandstone is quarried from the Potsdam Formation at St. Canut, north of Montreal, by Indusmin Limited. It is crushed, screened, and beneficiated by attrition scrubbing, flotation and magnetic separation to produce high purity silica for glass-making, foundry uses, silicon carbide and ceramics. The quartz grains vary from subangular to rounded. Ultimate quarry size will be 1100 m by 300 m by 15 m deep. Indusmin has further reserves of Potsdam Sandstone at nearby Ste. Scholastique, and a deposit of high purity Grenville quartzite at St. Donat 80 km northwest of St. Canut.

Indusmin Limited, Midland, Ontario

In 1970 Indusmin Limited commenced production of high purity quartzite from Badgeley Island in northern Georgian Bay, 6 km west of Killarney, Ontario. The quartzite deposit is in the Bar River Formation, at the top of the Huronian sequence of Late Precambrian age.

Lump quartzite is shipped by lake boat to Canadian and American destinations for the manufacture of ferrosilicon. The finer material produced in crushing is shipped to a grinding plant at Midland, at the south end of Georgian Bay, where it is further processed by drying, grinding, screening and air-classifying to make glass-grade silica sand and silica flour for ceramic and other uses. Photo 9 shows the Badgeley Island crushing plant and boat loading conveyor, and stockpiles of fine and coarse quartzite.

The deposit consists of massive, dense, fine to medium grained white quartzite in a nearly vertical band with a few impure lenses of diabase and amphibolite. Ultimate quarry development is expected to be over a length of 700 m and a width of 200 m. Figure 22 is a geological plan of the island.

Development of the deposit is recorded by M.A. Vos (1981, p. 4-6). Typical composition of the quartzite is given in Table 37.

Steel Brothers Canada Limited
The Selkirk Silica Division of Steel Brothers Canada Limited operates a sandstone quarry on Black Island in Lake Winnipeg, Manitoba. The sandstone is nearly white, poorly consolidated, and consists predominantly of rounded quartz grains. It requires drilling and blasting, and is loaded directly into a washing and screening plant. After dewatering, the sand is shipped by barge 130 km to a finishing plant at Selkirk on the Red River. Products are used in glass-making, fibreglass, foundry and other industrial uses.

SIL Silica Limited
SIL Silica Limited produces a sand product primarily for fiberglass by dredging a deposit of dune sand near Bruderheim, 35 km northeast of Edmonton. The sand is washed, screened and dried but otherwise unbeneficiated.

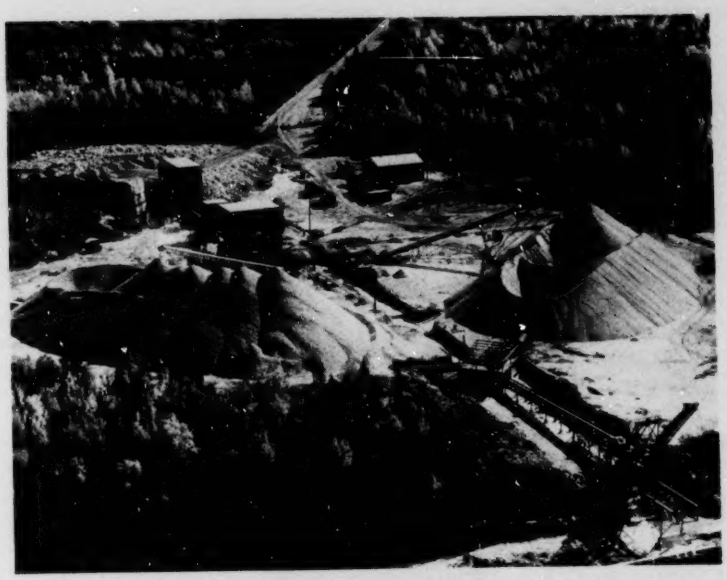


Photo 9 Indusmin Badgeley Island Crushing Plant. Showing coarse and fine quartzite stockpiles and boat-loading conveyor (photo by George Hunter).

Table 38 Some Silica Producers of Canada and the United States

(Note: Numbers correspond to locations on Figure 23).

Canada

NOVA SCOTIA
1) Nova Scotia Sand & Gravel Ltd., Brazil Lake
QUEBEC
2) Indusmin Ltd., St. Canut
ONTARIO
3) Indusmin Ltd., Midland
MANITOBA
4) Steel Brothers Canada Ltd., Selkirk
ALBERTA
5) SIL Silica Ltd., Bruderheim

United States

ARKANSAS
6) Malvern Minerals, Hot Springs
CALIFORNIA
7) Wedron Silica Division, Byron
8) Ottawa Silica Co., Oceanside
9) Texas Mining Co., Riverside
CONNECTICUT
10) The Feldspar Corp., Middletown
11) Ottawa Silica Co., Ledyard
FLORIDA
12) The Feldspar Corp, Edgar
GEORGIA
13) The Feldspar Corp., Monticello
ILLINOIS
14) Manley Bros. of Indiana Inc., Chesterton
15) Ottawa Silica Co., Ottawa
16) Illinois Minerals Div., Georgia Kaolin; Elco
17) Tammsco Inc., Tamms
18) Unimin Corp., Utica

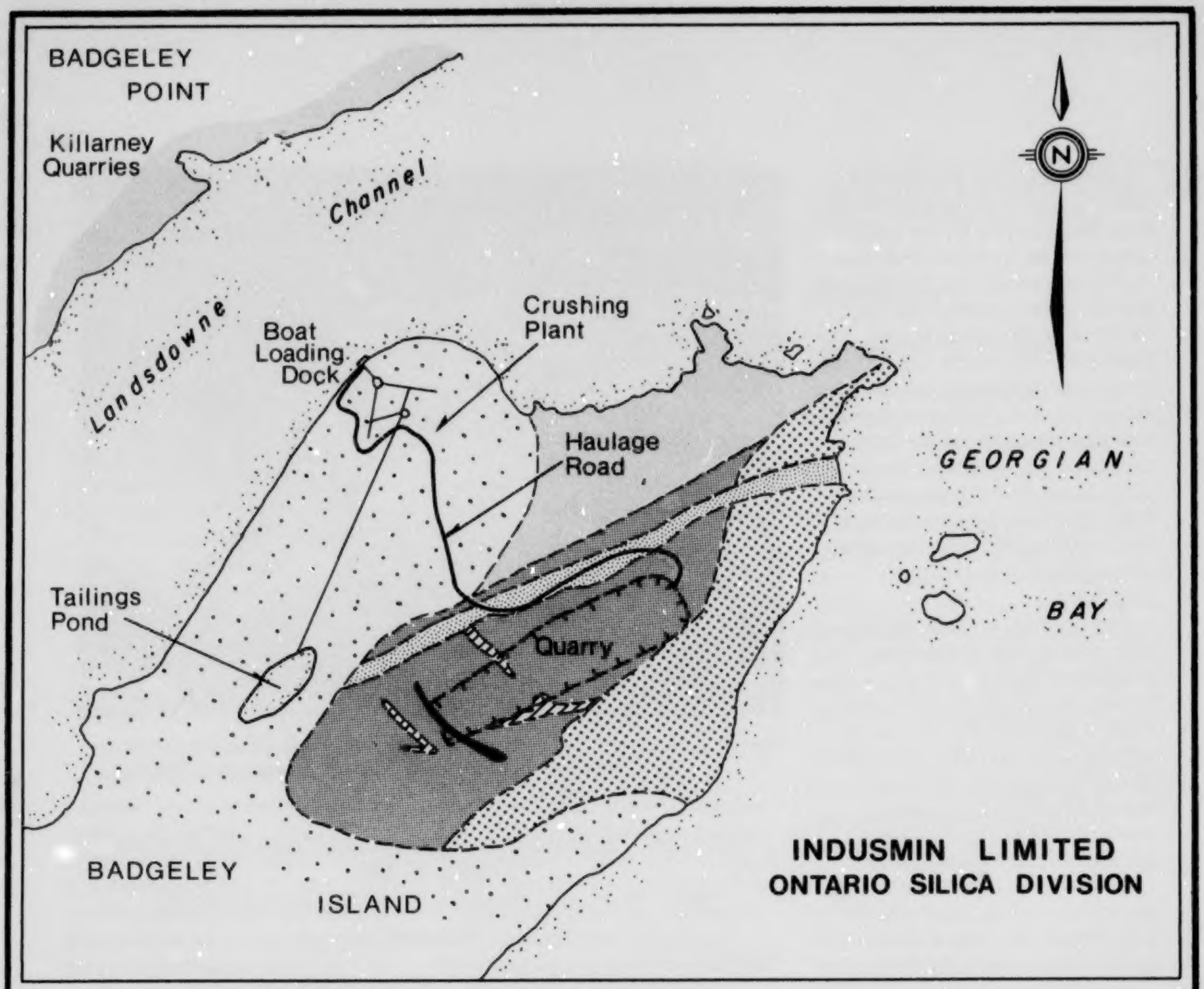


Figure 22

GEOLOGY MAP OF NORTHEAST BADGELEY ISLAND, GEORGIAN BAY, ONTARIO

After D.G. Minnes & D. MacGregor

Legend

PALEOZOIC

⁘ Ordovician limestone

PRECAMBRIAN

▬ Diabase

▒ Killarney granite

▨ Amphibolite

HURONIAN SUPERGROUP

■ BAR RIVER orthoquartzite

░ GORDON LAKE sandstone

☐ LORRAIN orthoquartzite

200 0 200 400
km

United States Producers

There are numerous producers of silica in the United States, many of which are listed by state in Table 38 and located on Figure 23. Deposits in Illinois, Michigan, West Virginia and Pennsylvania are of special interest because they enjoy markets in Ontario. Principal sources of Ontario imports are briefly described in the following notes.

Table 38 Some Silica Producers of Canada and the United States (cont'd)

- LOUISIANA
  - 19) Ottawa Silica Co., Dubberly
- MICHIGAN
  - 20) Great Lakes Minerals Co., Erie
  - 21) Ottawa Silica Co., Rockwood
  - 22) Manley Bros. of Indiana Inc., Bridgman
- MINNESOTA
  - 23) Unimin Corp., Ottawa
- MISSOURI
  - 24) PGS Corp., Pacific
  - 25) PGS Corp., Augusta
  - 26) Unimin Corp., Crystal City
- NEVADA
  - 27) Manville Corp., Overton
- NEW JERSEY
  - 28) PGS Corp., Millville
  - 29) New Jersey Pulverizing Co., Bayville
  - 30) Unimin Corp., Dividing Creek
  - 31) South River Sand Co., East Brunswick
- NORTH CAROLINA
  - 32) The Feldspar Corp., Spruce Pine
  - 33) Lawson United Feldspar & Mineral Co., Spruce Pine
  - 34) Kings Mountain Mica Co., Kings Mountain
  - 35) IMC (Sobin), Spruce Pine
  - 36) Harris Mining Co., Spruce Pine
- OHIO
  - 37) PGS Corp., Dundee
  - 38) Central Silica Co., Zanesville
  - 39) Walter C. Best Inc., Chardon
- OKLAHOMA
  - 40) PGS Corp., Mill Creek
  - 41) Arkhola Sand & Gravel Co., Muskogee
- PENNSYLVANIA
  - 42) PGS Corporation, Mapleton Depot
  - 43) PGS Corp., Utica
- SOUTH CAROLINA
  - 44) PGS Corporation; Cayce
  - 45) Wedron Silica Division, Lugoff
- TENNESSEE
  - 46) Wedron Silica Division, Sewanee
- TEXAS
  - 47) PGS Corp., Brady
  - 48) PGS Corp., Three Rivers
  - 49) Ottawa Silica Co., Kosse
  - 50) Wedron Silica Division, Cleburn
  - 51) Texas Mining Co., Brady
- VIRGINIA
  - 52) Unimin Corp., Gore
- WASHINGTON
  - 53) Industrial Mineral Products Inc., Ravensdale
- WEST VIRGINIA
  - 54) PGS Corporation, Berkeley Springs

Ottawa Silica Company, Illinois

Ottawa Silica Company has been a source of high purity silica since 1911 from its operations in the St. Peter Sandstone near Ottawa, Illinois. The sandstone is Lower Ordovician in age, flat-lying, massively bedded and of high natural purity. Quartz grains are well rounded, apparently the result of several stages of aeolian and fluvial reworking. The friable deposits are worked by hydraulic mining techniques, and the plant process includes washing, screening and drying. Elaborate beneficiation is not required. A number of glass plants in the Toronto-Hamilton area have used silica sand from this source for many years.

Ottawa Silica Company, Michigan

Sylvania Sandstone is quarried at Rockwood, Michigan, by Ottawa Silica Company. It supplies glass sand to plants in Wallaceburg and Hamilton.

PGS Corporation, West Virginia

Oriskany Sandstone is quarried at Berkley Springs by Pennsylvania Glass Sand Corporation. It is imported into the Niagara Falls, Guelph, and Toronto areas.

PGS Corporation, Pennsylvania

Oriskany Sandstone is also quarried at Mapleton, Pennsylvania, and is imported for glassmaking in the Toronto area.

Bank Sands, Michigan and Ohio

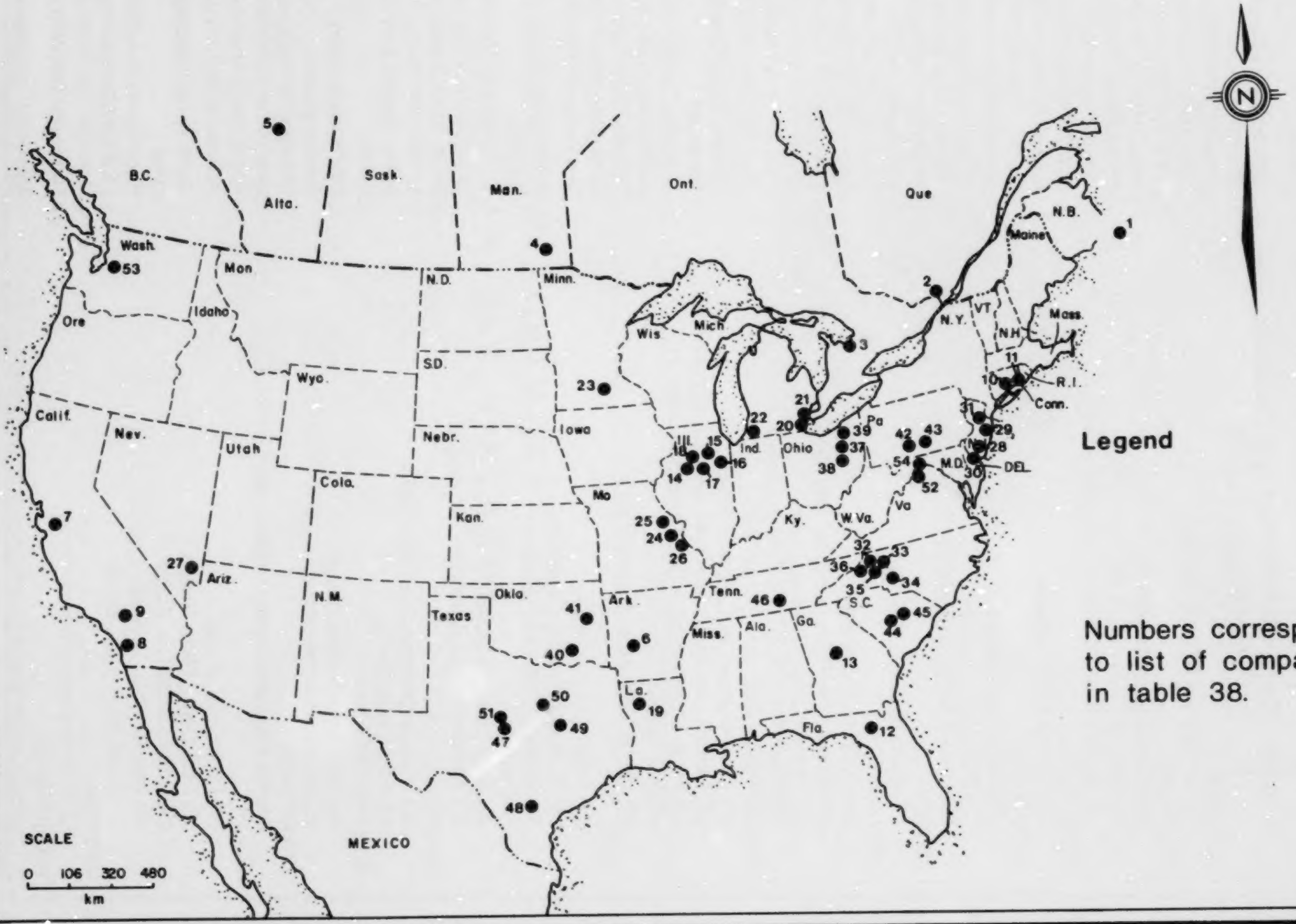
Bank sands from Muskegon, Michigan, and northern Ohio are imported into Ontario for foundry sand and fiberglass.

Mining Technology

Open pit excavation of friable sandstones or unconsolidated

Figure 23

PRINCIPAL PRODUCERS OF SILICA



Legend

Numbers correspond to list of companies in table 38.

sands, and conventional quarrying of harder sandstones and quartzites, is normal for silica operations in Canada. Excavation of the dune sands north of Edmonton by SIL Silica is accomplished by backhoe; most of the deposit is below the water table. Front end loaders are used for sand removal at Brazil Lake in Nova Scotia. Conventional bench quarrying with drilling and blasting is necessary in Potsdam Sandstone at St. Canut, Quebec, and in Precambrian quartzite on Badgeley Island, Ontario, and the loosely consolidated sandstone of the Winnipeg formation at Black Island in Manitoba.

In the United States, poorly consolidated sandstones such as the St. Peter in Illinois can be mined by hydraulic methods. The sandstone face is excavated by high pressure water streams, and the sand slurry is removed to the plant by pipeline. Occasionally underground mining by way of horizontal adits or shallow declines or vertical shafts are used where overburden thickness is excessive.

Processing Technology

Silica occurs in nature in both the crystalline and amorphous states. Crystalline silica is found in many different forms such as natural sands, friable sandstones, hard compacted and cemented sandstones, quartzite and quartz. The geological origin of any silica deposit can have a significant influence on the processing method necessary to prepare it for market.

Silica has many industrial applications and silica processing plants tend to be large. The production of silica fillers or extenders from crystalline silica sources usually represents only a small portion of total plant production.

Finely ground silica is used in ceramics, household cleansers, autoclaved concrete blocks, white cement, asbestos cement and calcium silicate bricks. Its filler use is limited to paints and plastics.

Amorphous or cryptocrystalline silicas occur in the United States where they find more extensive use in filler applications. Synthetic silicas, produced by chemical processes from materials such as sodium silicate, also find use as fillers in many industrial applications.

Natural Sands

Silica from natural sand deposits is often impure; it may vary both in grain size distribution and chemical composition. However, in some cases it can be upgraded to commercial specifications simply by washing, sizing and magnetic separation. Where the sand is mixed with feldspathic minerals, flotation can sometimes usefully be employed to produce both silica sand and feldspar products.

Sandstone

Sandstone deposits are common in eastern Ontario and Quebec. They range from friable loosely consolidated sandstones to compact dense varieties. Friability is often a function of the degree of post-deposition weathering which causes a breakdown of the bonding or cementing material between the quartz grains.

Highly friable sandstones can be easily reduced to their natural grain size in autogenous grinding mills after primary crushing, or in rod or ball mills following secondary crushing. Hammermills are also used.

Sandstones invariably contain contaminants, usually as part of the cementing materials which can be calcareous, aluminous or siliceous in composition.

Processing of silica sand is usually directed primarily towards the production of sands suitable for glass manufacturing and foundry uses, the two largest markets for high purity sand. Sandstones are the most common sources of silica for these applications.

The degree of required processing can vary greatly. Some sandstones, such as the St. Peter Sandstone of Illinois, are very friable and of high purity. They can be upgraded to glass or foundry grade quality by simply washing, desliming, screening and drying. High pressure hydraulic mining methods may be adequate in such sandstones.

Other sandstones contain iron bearing minerals requiring removal by magnetic separation or froth flotation. Selection of the processing methods is based on the mineralogical composition of the contaminants. Some sandstones are treated by leaching with sulphuric or hydrochloric acids. Acid leaching is often employed for iron stained sands that cannot be upgraded by magnetic separation or froth flotation.

Attrition scrubbing at high solids density is often effective in removing coatings or cementing materials from sand grains. This technique is also employed to prepare the silica sand for froth flotation, eliminating the formation of slimes and conditioning the grain surfaces for the froth flotation process.

Quartzite

Quartzites occur in massive bodies in eastern Canada and in some cases are a source of silica for the production of glass grade silica. Like sandstones, quartzites occur in different forms ranging from coarse crystalline friable quartzites to fine grained very densely compacted varieties. Quartzite of sufficient purity is also a good source of lump silica for ferrosilicon production and for production of silicon carbide.

Quartzites are processed using several stages of crushing followed by rod or ball mill grinding. Crushing and grinding of quartzite is much more difficult than for sandstone. In sandstone, crushing and grinding is designed to reduce the stone to its natural grain size by destroying the material binding the grains together. In quartzite, where the bonding material is as strong as the grains themselves, it usually means breaking the grains to achieve the desired particle size.

Quartzites, like sandstones, can be very pure or can contain iron, titanium and aluminous minerals. As in sandstones, the grains of quartz are bonded with a cementing material which may have been weakened by weathering processes, leaving a friable quartzite, or which may have resisted weathering and retained a very strong bond difficult to break. The grain structure of quartzite is usually very angular and the individual grains fit together like the pieces of a jigsaw puzzle with the binding material filling the interstitial spaces between the grains.

Quartzites of high purity may not need beneficiation other than crushing, grinding and screening to the desired particle size, followed by the removal of minus 150 mesh fines resulting from the comminution process. Process fines can be used in applications such as autoclaved concrete blocks, or the production of white cement. Alternatively they can be ground further for use in scouring powder, ceramics, fiberglass and fillers, if colour and chemical purity is satisfactory.

Quartzites containing impurities exceeding the limits for "glass grade" quality must be amenable to further beneficiation by magnetic separation and/or flotation.

Quartz

Quartz deposits are not normally exploited for glass sand, but may be developed as a source of lump silica used in the production of ferrosilicon.

Quartz deposits of very high chemical purity are a potential source of silica in the production of optical, opthalmic glasses, or as feed in the manufacture of synthetic quartz crystals.

Because of the angular grain shapes, products derived from quartz or quartzite are not suitable as foundry sand. However, if sufficiently pure, they can be used in the making of glass, ferrosilicon, silicon carbide, and abrasives; and when finely ground as fillers in plastics, paints, household cleansers, etc.

Wet or Dry Processing

Depending on the purity and character of the silica source, either wet or dry processing can be applicable. The choice is usually dictated by the type of impurities contained in the rock or the applications for which the products are intended. Dry processing of silica sands requires extensive environmental protection because of the health hazard of silica dust, while wet processing is more energy intensive because of the additional cost of drying (Figure 24).

Beneficiation Processes

Natural silica sources, be they sandstones, quartzites or quartz, often contain impurities that are detrimental in the applications in which they are to be used. These impurities can take many forms, and they reflect the geological history of the material.

Beneficiation processes for removal of these impurities must be based on a thorough knowledge of the mineralogical composition of the silica source. Only silica sources where the impurities exist as discreet minerals can be successfully processed.

A first step is to determine the particle size at which the impurities are liberated from the silica grains. Frequently, the contaminating minerals are present as attachments to the silica particles or fill cracks in the grains. This is particularly common with sandstones.

In other cases, the contamination is in the quartz grain itself, making it impossible to remove. The impurity may be in the silica crystal structure itself, having dissolved and re-crystallized in the silica crystal during formation. This type of contaminant is commonly referred to as being in "solid solution".

Based on mineralogical examinations, it can be determined which particular process will be most effective in separating the impurities. If they are magnetic or paramagnetic then high intensity magnetic separation may be effective. If nonmagnetic, froth flotation can often be employed as the separation process. Silicas stained with iron oxides or iron hydroxides can frequently be upgraded by attrition scrubbing and/or leaching with various acids.

Silica is a low value commodity and is therefore sensitive to the cost of processing. Extensive processing is usually not warranted for deposits far away from consuming markets. The combination of high processing and distribution costs will generally not allow effective competition. In contrast, a deposit of lower quality located close to the consuming industries may be economic, in spite of higher costs for upgrading the material to the desired quality.

Filler Production

Production of silica fillers is by conventional grinding processes. Silica is a very hard, abrasive mineral that is difficult to grind. Depending on the purity required, fine grinding may be conducted in ball or pebble mills. The most important product criteria for silica fillers are colour, particle size and purity. Most high quality silica fillers (produced from crystalline silica) are ground with pebble mills operated in closed circuit with air classifiers.

Finely ground silicas are used in ceramics, fiberglass, white cement, household cleansers and

CONCEPTUAL FLOWSHEET – SILICA SAND AND FILLER PLANT
DRY OR WET PROCESSING ALTERNATIVES

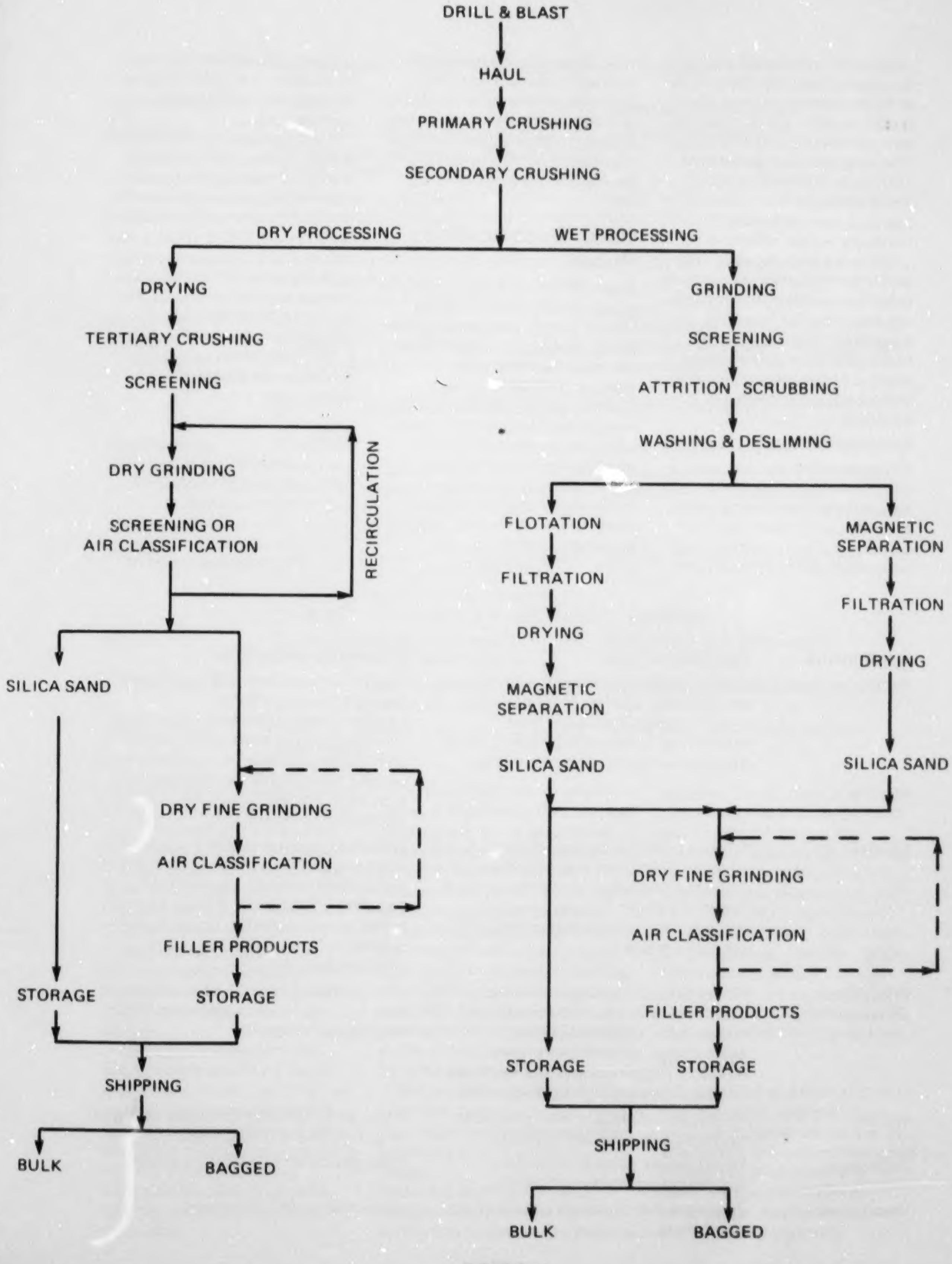


FIGURE 24

construction materials such as autoclaved concrete blocks. All of these applications require products with a specific particle size, chemical purity and colour. The most common grades are 100 mesh, 200 mesh and 325 mesh products. These products can be produced by conventional dry pebble mill grinding.

Silica is a very abrasive mineral requiring careful equipment selection and design of processing and materials handling equipment. Installation of ceramic, rubber or polyurethane liners is commonly employed to protect equipment against abrasion.

Environmental Protection

Dry processing of silica sand and filler grade silica requires extensive environmental protection devices to meet clean air standards. Dust collection has advanced rapidly in recent decades. Improved equipment design and materials handling technology have contributed significantly to minimizing the effect of dust emissions in the processing of silica and achieving the air quality standards required by law.

Uses, Specifications, Prices

Silica sand is extensively used in glass making, where it constitutes the major part of the glass batch. As foundry sand it lines the moulds in the casting of iron, steel, and nonferrous metals.

Finely ground silica is used in many industrial products. Filler applications are a relatively small portion of its total use. Finely ground silica is used extensively in non filler applications such as ceramics, building materials, refractories, abrasives, mortar and plasters.

Finely ground natural silica, tripoli and novaculite compete with other minerals in filler applications.

Finely ground crystalline silica is used in filler applications to provide properties not readily obtained with other mineral fillers. The natural abrasiveness of silica is such that, in many applications, it cannot be used effectively because of high wear on processing equipment. Its filler use is therefore restricted to applications where the same results or properties cannot be readily achieved with other fillers.

Paint

The paint industry is the largest consumer of high brightness, fine particle size silica.

Silica paint extenders are produced from crystalline silicas such as sandstones or quartz-

Table 39 Major Filler Applications for Silica

Applications	Function	General Specifications
Paint	Silica is used in paints to provide good scrubbability and film toughness. In exterior paints, it provides good weathering. Used in block fillers, porch and floor enamels and traffic paints.	Grades ranging from 325 mesh to 10 microns are used. Some cryptocrystalline grades of silica have very fine sizes with low average particle size. Silica ground from crystalline silica usually has a higher average particle size. High brightness and low oil absorption is essential.
Plastics	Silica is used in different polymer systems. Silica provides excellent dielectric properties, compression and flexural strength. It is used in potting compounds made from epoxy or polyester resins.	Natural or cryptocrystalline grades of silica are used in plastics. Some grades are surface coated or treated with coupling agents to aid dispersion and better bonding with the polymer. High brightness grades of 325 mesh to 5 microns are used.
Putty, Caulks, Sealants	Finely ground silica is used in epoxy based sealants and silicone caulking compounds. Used in electrical applications, silica provides good dielectric properties and has low binder demand allowing high loading levels.	Fine grades of 10 to 30 microns particle size are used in this application. High brightness is required.
Rubber	Finely ground silica is used in silicone rubbers as an extender pigment.	Fine, 30 to 10 micron products are used. High brightness is important.
Adhesives	Finely ground silica is used in the compounding of vinyl adhesives.	Fine ground 40 to 10 micron grades.
Wood fillers	Finely ground silicas are used in paste wood fillers.	Grades from 30 to 5 microns.

Table 40 Minor Filler Applications for Silica

Applications	**Function**	**General Specifications**
Asphaltics	Fine natural silica is used in asphaltic coatings such as for flat roofing and driveway coatings.	100 to 325 mesh grades.
Buffing compounds	Finely ground silica is used in bar or cake buffing compounds used in metal polishing.	Very fine 30 to 10 micron grades. Tripoli type of silica is preferred.
Foundry Mold Washes	Finely ground silica is used in foundry mold washes to improve surface quality of castings and to provide good parting.	200 and 325 mesh grades.
Household cleansers	Finely ground silica is a major ingredient in many dry household cleansers, abrasive hand soaps, etc.	200 mesh fine ground silica. High brightness and good flow properties are essential.

Table 41 Major Non-Filler Applications for Fine Silica

Applications	**Function**	**General Specifications**
Ceramics	Finely ground silica is a major ingredient in many ceramic products such as sanitary ware, dinnerware and electrical porcelain.	Grades from 200 to 400 mesh. High purity, low iron, white firing.
Glass	Fine silica is used in the manufacture of reinforcing and textile fiberglass in which it is a major constituent of the glass batch.	325 mesh grade. Low in iron and alkalies.
Bricks	Finely ground silica is used in the manufacture of silica-lime brick	200 mesh silica. Low purity is adequate.
Concrete block	Fine silica is used in the manufacturing of autoclaved concrete block.	100 to 200 mesh silica of low purity.
White cement	Fine silica is used in the manufacture of white cement.	200 mesh product. Medium purity.

ites and from naturally occurring fine grained cryptocrystalline silicas like tripoli and novaculite, sometimes referred to as amorphous silicas. These materials differ in their geological origin but have essentially the same physical properties. The cryptocrystalline filler grades have a finer average particle size than silica fillers ground from sandstone, quartzite or other quartz bodies.

Silica paint extenders are used in trade sales and industrial paint formulations. Their primary function is to extend the primary pigment, titanium dioxide. Silica contributes properties such as wear resistance, scrubbability, film toughness, flatting, and resistance to chemical attack.

Silica is hard, chemically inert, with high brightness and low oil absorption. It is used in flat exterior house paints, sealer primers, floor and porch enamels, concrete paints, block fillers, traffic paints and chemical resistant coatings. Its high abrasiveness prevents its universal use as a paint extender and it is therefore viewed as a specialty extender. It is used in paints where the properties contributed by the silica cannot be achieved by other pigment extenders.

Silica paint extender additions vary from formulation to formulation depending on the end properties required in the paint.

Prices

The price structure of paint grades is based on particle size, with prices increasing as particle size decreases. High brightness is a critical requirement in most paint applications.

Finely ground silicas suitable for use as paint extenders are marketed at prices ranging from U.S. $80 to $290 per tonne in 22.7kg (50 lb) paper bags f.o.b. production site. The lower price reflects the coarser 325 mesh grades while the higher price reflects the high brightness 90-92 G.E. superfine 5 micron grades.

Plastics

Silica is used as a filler in phenolics, polyester, epoxy and nylons. Silica has a natural low oil absorption, is inert and has good dielectrical properties. It is therefore used in products where these properties are important. Silica improves compression, flexural strength and dimensional stability. Other uses are in the epoxy potting and encapsulating compounds used by the electronics industry.

Surface treatment with silanes or titanate coupling agents markedly improves the performance of silica in plastics. Surface treatment is popular with filler grades produced from cryptocrystalline silicas such as tripoli and novaculite. Coated grades of tripoli and novaculite are produced by several United States producers. However, there is no documented data indicating that silica fillers produced from sandstones or quartzites are coated or treated with coupling agents.

Prices

Silica filler grades used in plastics are similar to the grades used in paint; the finer grades are preferred. Silica fillers treated with surface coatings or coupling agents are considerably more expensive.

Uncoated grades range from U.S. $140 to $300 per tonne. Surface treated grades are marketed at premiums of U.S. $150 to $400 above the uncoated grades. Prices are for shipments in 22.7kg (50 lb) paper bags f.o.b. production or shipping point.

Putty, Caulks & Sealants

Finely ground silicas find application in epoxy sealants used in the electronics industry. Silica improves the dielectric properties of these sealants. Silica is also used in white silicone caulking compounds. Its low oil absorption and high brightness allows high loadings without affecting the colour or application properties of the sealant.

Prices

High brightness, high purity, fine particle size silicas are used in these applications. These grades are sold at prices ranging from U.S. $140 to $300 per tonne in 22.7kg (50 lb) paper bags f.o.b. point of shipment.

Rubber

Finely ground high brightness silica is used to extend silicone rubbers. Its low oil absorption, easy dispersibility and compatibility with silicone rubber offers an advantage in this application, but its main function is to reduce cost. It is used with other reinforcing fillers such as synthetic silica in silicone rubber.

Prices

Fine high brightness grades produced from high purity crystalline silica are marketed for use in rubber. Grades 30 microns and finer are required in this application, and these grades are sold at prices ranging from U.S. $130 to $290 per tonne packaged in 22.7kg (50 lb) paper bags.

Adhesives

Adhesives are a minor application for silica fillers. Silica fillers are used in vinyl adhesives and to a lesser extent in epoxy based adhesives. The market is small and fragmented and does not represent a significant silica market.

Grades similar to those used in paints and plastics are employed.

Wood Fillers

Finely ground silicas are used in paste wood fillers for filling open grained wood, cracks and surface imperfections. The low oil absorption and particle shape of silica assists in good filling and hardening properties.

Grades similar to those used in paints are used in this application. The preference is for products ground from sandstone or quartzite.

Asphaltics

Low grade ground silica is used in asphaltic coatings such as in re-coating or repairing driveways or in roofing patch compounds. Silica is used because of its hardness and inertness. It also provides good anti-slip and weathering properties.

Low grade silica or silica by-products can be used in this application. Other minerals may be used and often the lowest cost inert filler available is employed.

Silica fillers for this application are usually 100 to 200 mesh, or finer, in particle size. These products may sell for U.S. $30 per tonne in bulk.

Buffing Compounds

Fine silica is used in stick, bar or cake buffing compounds used in the buffing or polishing of metals. Only grades of very fine particle size are used. This is a minor and specialty application. Preference is given to tripoli.

No special grades are produced. The silicas are the same as those used in other filler applications.

Foundry Mould Washes

Fine silicas are used in mould washes to coat foundry moulds in centrifugal casting of heavy wall steel tubing. The mould wash is applied to the mould to improve the surface quality of the casting and to obtain easy separation of the casting from the mould.

This is a specialty market and a very minor application for silica fillers. Mould washes are sold in prepared form to foundries. Silica fillers 200 mesh and finer are used.

Household Cleansers

Fine silica is used as one of the major ingredients in dry package household cleansers. Products used in this application must be of high wet and dry brightness and exhibit good flow properties. The flow properties are achieved by close control of the desired particle size of the product.

Other minerals such as feldspar can be used in this application if they are of the required brightness.

Acceptable grades for household cleansers are of high purity and brightness and have a particle size in the 150 to 200 mesh range.

Products for this application

are marketed at prices ranging from U.S. $40 to $60 per tonne in bulk, f.o.b. shipping point.

Ceramics

Finely ground silica of high chemical purity is an essential ingredient in the production of all types of ceramics. It is used in conjuntion with other minerals such as kaolin, ball clay, fire clay, talc, feldspar and nepheline syenite.

Good chemical purity, controlled particle size, and white, speck-free fired colour is important for ceramic grade silicas. Typical grades are 200, 325 and 400 mesh depending on application.

Prices

Prices for these products range from U.S. $40 to $70 per tonne in 22.7kg (50 lb) paper bags.

Glass

Finely ground high purity silica of low iron, alumina and alkali content is used in the manufacture of reinforcing and textile fiberglass. Silica together with the other batch ingredients is melted to provide the molten glass from which the fibers are drawn.

This application is a major market for finely ground silica in areas where there is a plant producing this type of fiberglass.

The chemical composition and particle size of the product must be controlled within specified limits.

Prices

Grades of silica used in this application are priced at U.S. $40 to $45 per tonne in bulk.

Bricks

Low purity silica ground to 150 to 200 mesh is used in the production of silica lime brick for residential and commercial construction. It is also used in manufactured exterior facing stone.

Low grade unbeneficiated silica can be used in this application. Silica rock may be crushed and further ground in ball or pebble mills. This is a low value application, of interest to silica producers located close to plants producing these products.

Prices

This grade of silica is marketed at prices of U.S. $25 to $35 per tonne in bulk f.o.b. production site.

Concrete Block

Grades similar to those used in silica lime brick are used in the production of autoclaved concrete block.

White Cement

Fine silica of medium to high purity is used in the production of white cements and mortars. Products must be low in alkalkis.

Grades suitable for this application are sold at prices ranging from U.S. $30 to $40 per tonne in bulk.

Production and Consumption

Canada

The most striking feature about silica, especially in Ontario, is its expanding level of consumption, and increasing cost and uncertainty of supply. About 70 percent (by value) of Ontario's

Table 42 Canadian Consumption of Silica by Use

	1957	1967	1976	1980
Smelter Flux	1,475,598	1,649,660	1,328,667	1,247,861
Glass Manufacturing (incl. fiberglass)	243,348	434,371	740,427	968,019
Foundry Sand	154,281	607,788	577,455	1,365,689
Ferrosilicon	127,978	90,038	—	—
Artificial Abrasives	113,829	138,014	143,895	130,461
Metallurgical Use	—	72,759	—	67,812
Cement Manufacturing	81,449	—	—	—
Concrete Products	—	20,594	12,064	63,254
Chemicals	24,308	20,964	19,966	38,603
Soap and Cleanser	11,156	—	—	—
Clay Products	6,440	—	—	—
Gypsum Products	—	38,972	8,932	8,850
Asbestos Products	—	28,094	—	—
Fertilizer, stock & poultry feed	—	29,232	54,351	4,172
Refractory brick, mixes, cements	—	—	—	512,416
Other	—	45,086	489,109	50,506
Total	2,238,387	3,175,575	3,374,876	4,457,643

Source: Statistics Canada

Table 43 Canadian Production and Trade in Silica

	1970		1980	
	QUANTITY tonnes	**VALUE dollars**	**QUANTITY tonnes**	**VALUE dollars**
PRODUCTION				
Ontario	1,380,000	2,766,000	936,000	9,565,000
Quebec	553,000	4,208,000	703,000	11,022,000
Other provinces	699,000	1,636,000	613,000	8,597,000
Total Canada	2,632,000	8,610,000	2,252,000	29,184,000
MARKET				
Glass and fiberglass			225,000	4,943,000
Flux			906,000	3,599,000
Ferrosilicon			146,000	1,154,000
Other			975,000	19,488,000
Total			2,252,000	29,184,000
IMPORTS				
From U.S.A.	1,161,000	5,231,000	1,194,000	17,408,000
EXPORTS				
To U.S.A.	59,000	149,000	63,000	601,000

Source: Statistics Canada

requirements are imported from the United States at costs which have more than tripled in the past ten years. Clearly, an opportunity exists for increased silica production in Ontario. Escalating freight rates from foreign sources are outpacing extra beneficiation costs that may be needed for effective utilization of local Ontario deposits.

While the major tonnage consumed in Ontario is low value flux for non ferrous metal smelters in northern Ontario, large quantities of silica are also consumed by glass, fibreglass, foundry, artificial abrasives and other industries in southern Ontario. The use of silica flour for filler purposes is minor compared with these industries. Total Canadian consumption for selected years is shown in Table 42; production is given in Table 43.

Production, consumption, imports and exports of silica for Ontario are estimated in Table 44 for 1977. Total value of all silica used in Ontario during 1979 was estimated to be $31 million delivered at consumers' plants (Minnes 1982, p.14). Two-thirds of this amount is the cost of transportation.

Table 44

Ontario Silica Production, Consumption, Trade, 1977

	QUANTITY tonnes	**VALUE $Can.**
PRODUCTION		
Metallurgical Flux	645,299	—
Refractory Brick	134,262	—
Glass, fiberglass, flour ferrosilicon	395,452	4,874,000
Total	1,175,013	
CONSUMPTION		
Total glass	350,624	
Foundry sand	240,695	
Refractory Brick	134,262	
Artificial Abrasives	49,369	
Soluble Silicates	17,131	
Concrete Products	6,191	
Other	29,517	
Total	327,789	
IMPORTS–Silica sands for		
Glass–Container	172,300	
flat	90,700	
Fiberglass	18,100	
Foundry	240,695	
Soluble Silicates	17,131	
Artificial Abrasives	49,369	
Total	588,285	
EXPORTS–Lump for Ferrosilicon	56,297	

Source: Statistics Canada; and D.G. Minnes 1982 p.13.

High purity silica for glassmaking and foundry sand has the highest value for bulk use, and about 60 percent is imported to Ontario from the United States. Specific statistics are lacking for consumption of silica fillers in Canada, but their principal use is in paint.

United States

Statistics for the United States are given by Tepordei (1982). A total of 27,192,000 tonnes of silica valued at U.S. $332,300,000 were shipped or consumed in 1981, representing an average value of $12.22 per tonne at the producer's pit or plant. The East North Central Region (which includes the states of Illinois, Indiana, Michigan, Ohio and Wisconsin) accounted for 40 percent of the total. Illinois and Michigan were the leading producing states in the nation, followed by New Jersey, Texas and California; and these five states represented 52 percent of the national total. Table 45 gives total United States production for recent years.

In 1981 a total of 91 producers operated 141 silica operations in the United States. Most had an annual production in excess of 300,000 tonnes; 40 operations accounted for 71 percent of the total tonnage produced. The ten leading producers in descending order of tonnage are listed below. Their combined production from 46 operations represented 61 percent of the U.S. total.

Pennsylvania Glass Sand Corp.
Martin Marietta Aggregates
Ottawa Silica Co.
Hardy Sand Co.
Owens-Illinois Inc.
Manley Brothers of Indiana Inc.
Oglebay Norton Co.
Unimin Corp.
Energy and Minerals Inc.
Badger Manufacturing Corp.

In 1981, consumption of silica in the United States was about 27 million tonnes valued at U.S. $332 million. About 40 percent was used for glass-making, 33 percent for foundry sand, 7 percent for abrasives and 5 percent for hydraulic fracturing sand. Statistics for consumption by use for 1980 are given in Table 46 for the North East, North Central and total United States.

Average value of silica sand in 1981 was U.S. $12.30 per tonne; for lump silica (silica gravel) U.S. $9.08 per tonne. Fillers had the highest average value of all silica products at U.S. $31.40 per tonne.

Of total silica produced in the United States, 57 percent was transported by truck, 33 percent by rail, and 6 percent by water.

In 1981 about 72 percent of all United States exports of silica went to Canada, mostly Ontario. Total United States exports were about 1 million tonnes.

Table 45 Silica Production in the United States

	QUANTITY tonnes	VALUE U.S. Dollars	VALUE per tonne
1977	28,444,000	210,600,000	$7.40
1978	29,795,000	248,800,000	$8.35
1979	30,394,000	283,800,000	$9.34
1980	26,850,000	293,100,000	$10.92
1981	27,192,000	332,300,000	$12.22

Source: V.V. Tepordei 1982, p.1

Table 47 Estimated Silica Filler Market, 1980-1985

	Total Canada and United States	Study Area
	Tonnes Annually	
Paint	55,000	35,000
Plastics	15,000	10,000
Rubber	5,000	3,000
Other	2,000	1,000
	77,000	49,000

The estimated market for silica fillers is given in Table 47.

Competitive Materials

Silica competes with calcium carbonate as a low cost filler in paints. Both have low oil absorption and hence good weathering properties, but calcium carbonate is normally preferred because of lower abrasiveness. However, in some interior paints silica improves scrubability because of its durability and inertness.

Calcined kaolin competes with silica in traffic paints, but is more costly and less durable.

Trends

Consumption of silica in paints is expected to show unspectacular growth. Its use in plastics is increasing more rapidly, and silica for this use has relatively high unit value.

Among the non-filler markets, silica use in glass and fiberglass is increasing at higher than average rates.

Escalating transportation costs from remote sources, particularly in the United States, are encouraging a reappraisal of possible Ontario sources. Now that transportation has become the major factor in the delivered price of silica, the extra cost of beneficiating impure Ontario sources is a less significant burden. A new domestic producer for the Ontario market seems likely.

Table 46 United States Silica Consumption by Use, 1980

	North East			North Central			United States Total		
	Tons (Thousands)	Value	Value per ton	Tons (Thousands)	Value	Value per ton	Tons (Thousands)	Value	Value per ton
Sand									
Glassmaking:									
Containers	2,142	$20,690	$ 9.66	2,330	$17,590	$ 7.55	8,862	$ 80,967	$ 9.14
Flat (plate and window)	88	968	11.00	492	3,629	7.38	1,689	13,472	7.98
Specialty	144	1,634	11.35	243	3,194	13.14	1,134	11,065	9.76
Fiberglass (unground)	73	601	8.23	542	4,129	7.62	747	6,175	8.27
Fiberglass (ground)	83	762	9.18	118	1,987	16.84	473	7,938	16.78
Foundry:									
Molding and core	657	7,860	11.96	6,449	45,991	7.13	8,488	65,803	7.75
Molding and core facing (ground)	67	632	9.43	57	255	4.47	153	1,156	7.56
Refractory	45	750	16.67	302	2,783	9.22	395	4,083	10.34
Metallurgical:									
Silicon carbide	1	15	15.00	144	1,470	10.21	156	1,603	10.28
Flux for metal smelting	—	—	—	10	29	2.90	141	1,095	7.77
Abrasives:									
Blasting	142	1,760	12.39	161	2,484	15.43	1,601	21,375	13.35
Scouring cleansers (ground)		14	—	88	1,663	18.90	163	3,051	18.72
Sawing and sanding	20	149	7.45	60	379	6.32	164	1,294	7.89
Chemicals (ground and unground)	73	802	10.99	211	1,802	8.54	456	4,739	10.39
Fillers (ground):									
Rubber, paints, putty, etc.	39	1,060	27.18	82	2,693	32.84	225	6,977	31.01
Ceramic (ground):									
Pottery, brick, tile, etc.	11	267	24.27	88	2,853	32.42	148	4,136	27.95
Filtration	71	1,087	15.31	63	720	11.43	234	2,788	11.91
Traction (engine)	17	178	10.47	188	1,354	7.20	403	2,958	7.34
Coal washing	2	18	9.00	10	111	11.10	43	404	9.40
Roofing granules and fillers	17	266	15.65	22	201	9.14	203	2,623	12.92
Hydraulic fracturing	1	11	11.00	379	6,968	18.39	1,177	24,023	20.41
Other	333	2,504	7.52	648	6,446	9.95	1,679	18,958	11.29
Total	4,027	42,030	10.44	12,680	108,700	8.57	28,730	286,700	9.98
Gravel:									
Metallurgical:									
Silicon, ferrosilicon	—	—	—	75	562	7.49	680	5,027	7.39
Filtration	—	—	—	8	160	20.00	19	209	11.00
Other	—	—	—	2	23	11.50	166	1,222	7.36
Total	—	—		85	745	8.76	865	6,458	7.47
Grand total	4,027	42,030	10.44	12,760	109.500	8.57	29,600	293,100	9.00

Note: Quantities are shown in thousands of short tons. Values are shown in thousands of U.S. dollars.
North East includes Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont.
North Central includes Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin.

Source: V.V. Tepordei 1982, p.12

9 Talc

Summary

The most unique property of talc is its softness. Hence it is used particularly where freedom from abrasiveness is important, such as for cosmetics and health-care products. However, its most important market is ceramics, where its ability to reduce firing temperatures and promote faster firing is expected to increase its utilization as a component of many ceramic bodies as fuel costs rise.

Commercial talcs have varied considerably in purity. Many have been mixtures of talc with tremolite, serpentine, magnesite and other minerals. Indeed, the talc products from the Gouverneur district of New York State have traditionally contained as much or more tremolite as talc, a mixture that established talc as a major filler in the paint industry. Other filler uses include plastics, sealants and jointing compounds, plus an important role as a pitch absorbant in paper pulp.

The trend today is towards increased purity in talc products, partly because of regulatory pressures in respect to alleged health hazards of certain fibrous minerals sometimes associated with talc.

Ontario's growing reputation as an important talc source became obvious in the early 1980s, first as a result of Steetley's successful entry into the pitch control market in the paper pulp industry of the Northeast, then as a result of Canada Talc's discovery of new reserves on which improved processing facilities could be based. Steetley's Timmins quarry and plant are also testing the cosmetics market with their products, and expanded production facilities are planned. The Canada Talc mine at Madoc has had the longest record of continuous operation of any mine in Canada, having been started in 1896, and under new management is expected to offer a range of high purity products.

Two longtime talc producers in Quebec have also upgraded their facilities in recent years. Bakertalc Inc. near Montreal produces a floated talc product for the paper industry plus lower grade products for other uses. Talc BSQ, the former Broughton Soapstone and Quarry Company Ltd., produces an off-white talc for the rubber and roofing industries plus soapstone blocks and slabs for refractory use, crayons and sculpture.

If market demand requires it, the Grenville rocks of southeastern Ontario are a major target area both for talc associated with dolomitic marble and with metavolcanic rocks. In northern Ontario the Archean volcanic belts of the Timmins area will continue to be good prospecting ground for talc-magnesite mineralization.

Estimated filler market for talc in the study area is 225,000 tonnes annually, largely in paint, paper, plastics, rubber, and putty, caulks and sealants (including drywall compounds).

Geology

Talc is a soft hydrous magnesium silicate mineral with the chemical formula $3MgO{\cdot}4SiO_2{\cdot}H_2O$. Pure talc theoretically contains 63.5% SiO_2, 31.7% MgO and 4.8% water. Talc is the standard reference mineral for number 1 in Mohs' scale of hardness. It has a specific gravity of 2.7 to 2.8, a perfect basal cleavage which gives it a greasy feel, and is translucent white to pale green or yellow in colour.

Commercial talcs may vary considerably in composition from that of the pure talc mineral but the physical properties should be similar. Indeed, many commercial products are mixtures of one or more of the minerals talc, tremolite, serpentine, chlorite, magnesite, diopside and others (Hewitt 1972, p. 4). Some impurities may be desirable; in certain talcs from New York State tremolite predominates in "talc" fillers widely used in the paint industry.

Talc is commonly formed by the alteration of serpentinized dolomite or ultramafic rocks by siliceous hydrothermal solutions. Talc formed in a dolomitic environment is usually white or light-coloured, and grinds to a white product of high brightness. Talc formed in ultramafic rocks may not yield a high brightness. Steatite is a fine grained massive variety of high purity talc; soapstone is a less pure but soft massive talc rock.

There are four talc producers in Canada: two in Ontario and two in Quebec. There are many talc producers in the United States and major production in 1982 was from Montana, Texas, New York, Vermont and California, in order of importance (anonymous 1982, p. 59).

Belts of dolomitic marble in the Grenville rocks of eastern Ontario are obvious prospecting areas for talc. So too are mafic metavolcanic rocks in the same region. Several dozen occurrences are described by Hewitt (1972), some of which are further mentioned on the following pages. A summary of occurrences in eastern Ontario is given in Table 48.

Talc occurrences in the mafic rocks of the Timmins area were reviewed by Kretschmar (1980). Occurrences in Kenora, Rainy River and Sudbury districts are described by Hewitt (1972).

Ontario Producers

There are two talc mines in Ontario: Canada Talc Industries Limited at Madoc in southeastern Ontario, and Steetley Talc Division of Steetley Industries (Canada) Limited at Timmins in northern Ontario.

Canada Talc Industries Limited

Canada Talc's mine at Madoc is the oldest continuously operated mine in Canada. Production commenced in 1896 in what was known as the Henderson Mine; in 1915 the Conley Mine was

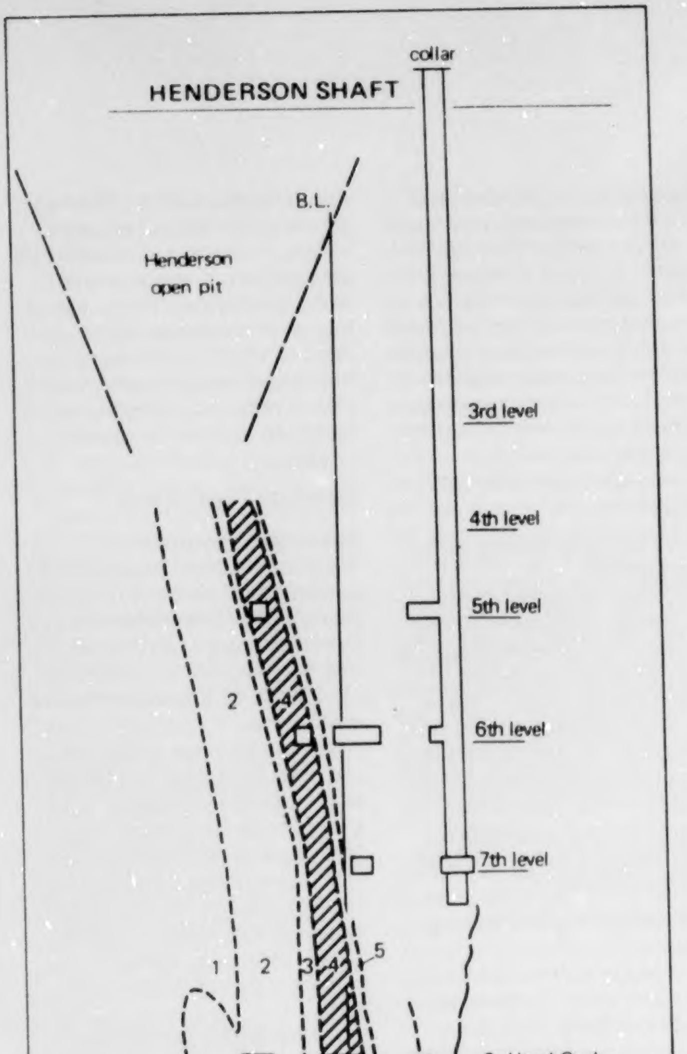
Table 48 Talc Occurrences in Eastern Ontario

Location	**Name**	**Type**
Frontenac County		
Palmerston Tp.		
Con. Vi, Lot 6	Ram Petroleums Ltd.	Tremolite schist
Pittsburgh Tp.		
Con. III, Lot 35 S½	Sparham Roofing Co.	Altered pyroxenite
South Canonto Tp.		
Con. 1, Lots 1, 2	Mosque Lake	Talc-tremolite marble
Hastings County		
Cashel Tp.		
Con. XII, Lots 16, 17	Madoc Talc & Mining Co. Ltd.	Chloritic talc schist
Con. XIII, Lot 16		Altered volcanic rocks
Con. XIV, Lots 15, 16		Altered volcanic rocks
Con. XV, Lots 15, 16		Altered volcanic rocks
Con. VII, Lot 2		Altered volcanic rocks
Elzevir Tp.		
Con. III, Lot 9	Fisher	Talcose volcanic rock
Con. III, Lot 11		Talcose volcanic rock
Con. IV, Lot 8		Talc veins in volcanics
Con. VI & VII, Lots 4, 5		Talc-actinolite
Faraday Tp.		
Con. X, Lot 11	Pipe Lake	Talc-tremolite marble
Grimsthorpe Tp.		
Con. IV, Lot 13S½		Talc-serpentine volcanics
Con. V, Lot 9		Talc veins in volcanics
Huntingdon Tp.		
Con. XIV, Lots 14, 15	Canada Talc Industries Ltd.	Talc and steatite in marble
Con. XIV, Lot 15	Price Mine	Sericite-talc schist in marble
Con. XIV, Lot 16	International Pulp Co.	Talc schist in marble
Lake Tp.		
Con. X, Lots 15, 16, 17, 18		Talc-tremolite marble
Madoc Tp.		
Con. XI, Lot 15		Talc schist in volcanics
Con. IV, V, Lots 20, 21	Eldorado Talc Mine	Talc-tremolite schist in marble
Wollaston Tp.		
Con. XI, Lots 8, 9		Tremolite-diopside in marble
Lanark County		
Lavant Tp.		
Con. III, Lot 24E½		Serpentinized dolomite
Pakenham Tp.		
Con. VI, Lot 6W½		Altered pyroxenite
Kaladar Tp.		
Con. V, Lot 2		Talc schist

opened on the same deposit. The Henderson and Conley properties were merged in 1937, and subsequently the underground workings were joined and operated as a single unit. The two properties are located in lots 14 and 15 respectively, in Concession XIV of Huntingdon Township. The company is owned by William R. Barnes Co. Ltd.

The deposit consists of a steeply-dipping tabular sheet of white foliated talc up to 18 m thick, but averaging about 5 m, and 200 m long east-west (Figure 25). Calcite, dolomite, pyrite and tremolite are minor impurities. The zone occupies the south limb of an anticline in dolomitic marble. Along its margins the foliated talc schist gives way to fine-grained massive green steatite. Elsewhere a white talcose tremolitic dolomite is also mined.

The Henderson property was worked by quarrying until 1908, then by shrinkage stoping underground. All mining on the Conley property has been underground. Seven vertical shafts and eight working levels have given access to the mine at various times, but only the most re-



CANADA TALC INDUSTRIES LTD.
(after Simandl and Ogden 1982)

LEGEND

1. Phyllite
2. Irregularly banded, micaceous tremolitic dolomite
3. Steatitized dolomite
4. Henderson type ore
5. Laminated, micaceous tremolitic dolomite
6. Siliceous beds with stromatolitic texture
7. Mottled blue dolomite
8. Undifferentiated thick dolomitic sequence

FIGURE 25 - VERTICAL SECTION, HENDERSON TALC ZONE.

cent shafts are still in use. Maximum depth of the workings is about 180 m. All milling is dry.

Exploratory surface drilling in 1982 southeast of the workings is reported to have outlined substantial additional reserves. These were being developed for quarrying in 1983.

Steetley Talc Limited

The Steetley Talc Division of Steetley Industries (Canada) Limited mines a talc-magnesite deposit in Penhorwood Township, 75 km west of Timmins. The mine was opened by Johns Manville Corporation in 1976 and acquired by Steetley in 1978.

The deposit is a magnesite-talc alteration zone in an area of Precambrian metavolcanic and metasedimentary rocks intruded by ultramafics. It is worked by quarrying during the summer months, and a stockpile of 40,000 tonnes is accumulated for the plant's winter requirements. Selective mining is necessary to avoid iron-stained and other discoloured rock. Reserves are reported to be in excess of 4 million tonnes (Clarke 1979, p. 32).

A talc flotation product is made at the mine and shipped by truck to Timmins for drying, fine grinding and bagging for shipment.

The major products are white and of high purity. The company has successfully established that its products are completely free of asbestiform minerals. Annual capacity of the plant is about 25,000 tonnes with plans for early expansion to 37,000 tonnes. Present sales are primarily for pitch control in paper pulp, and for filler in paint and plastics. A major target is the cosmetics market in the United States.

Other Ontario Occurrences

Ram Petroleums Limited

A small mill has recently been completed north of Clarendon on the west side of Highway 509 at its junction with a bush road that gives access to a talc-tremolite deposit 3 km to the west. The deposit is in Lot 6, Concession VI, Palmerston Township. A zone of talc-tremolite schist 15 m wide can be traced over a length of 300 m. Talc comprises about 10 percent. The company hopes to market an off-white product, essentially tremolite, for use in special asphalt and concrete applications.

Madoc Talc and Mining Company Limited

In 1938 this company sank a vertical shaft 27 m deep on a variable deposit of green fine-grained chloritic-talc schist in Lot 17, Concession XII, Cashel Township, Hastings County. The deposit varies up to 20 m in width and can be traced over a length of 3 km (Young 1982). Mine products were gritty and grey, suitable only for low grade uses (Spence 1940, p. 76).

Eldorado Mining and Milling Company

The main workings of the Eldorado talc mine are on the east bank of the Moira River in Lot 20, Concession V, Madoc Township, Hastings County. The mine was worked from 1911 to 1920. Two shafts gave access to underground working levels at 20 m and 60 m below surface.

The deposit is a pale grey-green to white talc-tremolite-dolomite schist 30 m wide; talc content averages about 20 percent (Hewitt 1972, p. 36).

In 1919 a separate mill circuit was installed to treat a 6 m zone of grey graphitic talc schist for the rubber and foundry trades (Spence 1940, p. 73).

Canadian Magnesite Mines Limited

A large magnesite-talc body in Deloro Township, 10 km south of Timmins in northern Ontario, has been extensively explored by Canadian Magnesite Mines Limited. The deposit is in altered serpentinite and has been defined over a length of 1800 m, a width up to 300 m, and to a drilled depth of 120 m. Mineralogically it consists of approximately 54 percent magnesite, 28 percent talc, 15 percent quartz, and 3 percent hematite. Laboratory studies towards the production of both talc and magnesite have been unsuccessful in sufficiently reducing the iron content for a dead-burned magnesia product.

Quebec Producers

Bakertalc Incorporated

Talc-magnesite deposits in Potton Township, Quebec, have been mined by Bakertalc Inc. or its predecessors since 1938. The Van Reet Mine, currently in production, is 130 km southeast of Montreal.

The deposits are zoned lenses up to 60 m wide and 100 m long in serpentinite dikes. From a serpentine core these lenses grade outwards through zones of talc-magnesite, schistose talc and talc-chlorite schist to a wall-rock of quartz-sericite-chlorite schist. Talc-magnesite comprises the bulk of the mined rock.

Four separate talc bodies were originally mined by raising and benching above a single adit 300 m long which was driven into one of the Sutton Mountains, part of the Appalachian chain. A 45 degree inclined shaft now gives access to underground levels at 60 m, 120 m and 180 m. Open stoping is performed from sublevels and finger raises.

Broken rock is trucked 16 km south to a mill at Highwater. Coarser products are crushed, dried and ground without beneficiation. About 5,000 tonnes of high quality grades are produced annually by flotation and fine grinding.

Talc BSQ Inc.

This company has been active since 1923 and presently operates two quarries near East Broughton in Quebec's Eastern Townships. The deposits are closely related geologically and geographically to the belt of serpentine rocks that contain Quebec's well-known asbestos deposits.

The soapstone is a soft medium-textured rock largely composed of varying proportions of talc, serpentine, chlorite and dolomite, and available in various shades of grey and green. As with the asbestos deposits, they have been formed by alteration of peridotite dikes.

Several low priced grades of off-colour talc are produced, and the stone is widely used for ornamental and carved artware as well as sawn and shaped industrial products.

Talc Producers in the United States

The United States is the world's largest talc producing and exporting country. In 1980 talc was produced from 31 mines in 12 states, of which Texas, Montana, Vermont and New York were most important in terms of volume, accounting for 81 percent of the total. Montana led in terms of value. Ten mines were active in California, 7 in Texas, 5 in Vermont and 4 in Montana. Pyrophyllite was produced at 5 locations in North Carolina and 2 in California (anonymous 1981, p. 77).

Filler-grade talcs are largely produced from deposits in California, Montana and Vermont. New York talc, long a standard source for paint extenders, finds its principal market with Texas talcs in the ceramic industry. The major producers are described in the following notes with plant locations shown on Figure 26.

New York

R.T. Vanderbilt Company Inc. is now the sole producer of talc in New York State and is the largest talc producer in the East. It commenced operations in 1948 on the west end of the commercial talc belt near Gouverneur in St. Lawrence County where talc mining was initiated in 1878 (Clarke 1979, p. 27).

The Gouverneur talc belt extends over a length of 15 km in the Adirondack Mountains. The talc deposits are inclined lenticular sheets in folds of silicified Grenville marble. They pinch and swell to a maximum thickness of 90 m and may extend to depths exceeding 600 m. Mineral composition consists of tremolite, talc, serpentine and anthophyllite, any of which may predominate locally but tremolite rock is the most common.

Tremolite-talc bodies are mined underground by stoping at various levels from 90 m to 330 m below surface and are accessible by vertical shafts. It is also mined on surface in the Arnold Quarry. Surface and underground production capacities are each rated at about 400 tonnes per day (Clarke 1979, p. 28).

Because of the variable proportions of the four major minerals, quality control is a vital part of the production process; numerous working faces are maintained and a program of frequent sampling at the faces and throughout the mill is practiced.

Various types of raw material, based on mineralogy, are separately mined, stored and milled. Drying precedes fine grinding in pebble and fluid energy mills, but no intensive beneficiation process is used. Various tremolite talc products are produced, containing 35 to 50 percent tremolite, which find special application in ceramic wall tiles and paints (Rieger 1981, p. 37).

Although the tremolite is virtually all prismatic, not fibrous, the company has been under heavy pressure from United States environmental agencies and has lost some of its markets as a result. For this reason as well as changing paint technology, ceramics are taking a gradually increasing share of the company's large production.

Vermont

There are three major talc producers in Vermont: Vermont Talc Inc., a subsidiary of OMYA Inc. and Pluess Staufer AG of Switzerland; Windsor Minerals Inc., a subsidiary of Johnson and Johnson; and Eastern Magnesia Talc Company, a subsidiary of Englehard Minerals and Chemicals Corporation.

Talc occurs as an alteration of pods and lenses of serpentinite. A zonal pattern is typical, where serpentinite forms the core of a lens, surrounded by successive shells of talc-carbonate up to 6 m thick and talc schist up to 1 m thick. Talc schist contains only minor chlorite, while talc-carbonate is essentially talc and magnesite with minor serpentine, magnetite, chlorite and sulphide minerals. Both types are medium to pale grey in colour, and the talc ranges from fine to coarsely flaky (Roe 1975, p. 1138). It is essentially free of asbestiform minerals.

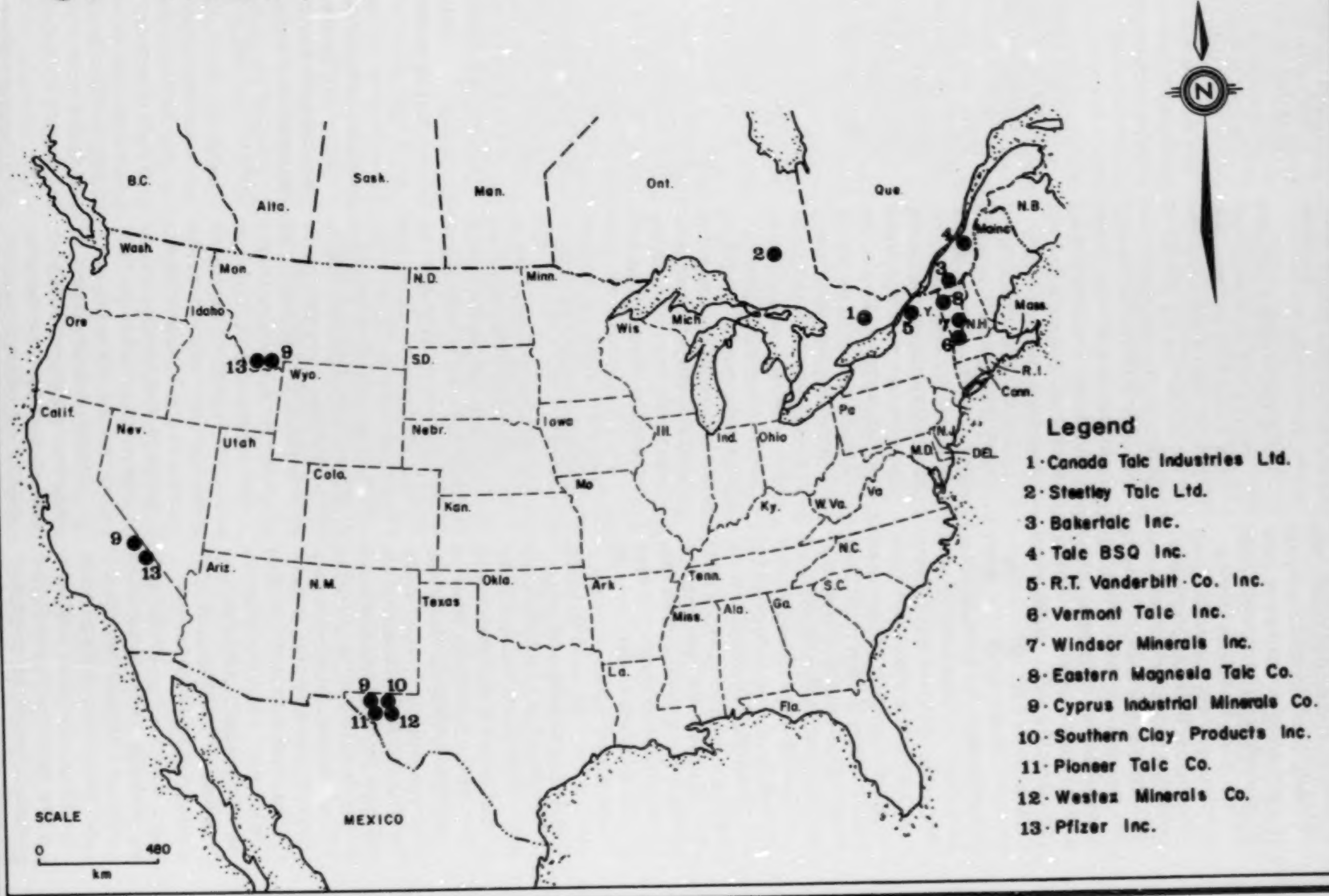
Vermont Talc Inc. was established in 1904. It produces an essentially pure talc product from an underground mine at Windham and a processing plant at Chester, 18 km from the mine. Processing has been by dry grinding in Raymond mills without beneficiation, but wet processing was planned for expanded mill facilities under construction in 1982. Products have been used primarily in coatings and putty, caulks and sealants, but the paper and cosmetics industries are targets for some of their new products. Annual capacity is 20,000 tonnes.

Windsor Minerals Inc. mines talc at two locations in southeast Vermont. Talc from a mine at Hammondsville is processed by flotation at West Windsor into cosmetic grades. Other industrial fillers are produced from a plant at Ludlow using talc from the Rainbow Argonaut Mine.

Eastern Magnesia Talc Company operates an underground mine at Johnson, supplying talc products for paper, paint, plastics, rubber and insecticides. The raw material is beneficiated by wet gravity tables and flota-

Figure 26

PRINCIPAL PRODUCERS OF TALC



Legend

1 · Canada Talc Industries Ltd.
2 · Steetley Talc Ltd.
3 · Bakertalc Inc.
4 · Talc BSQ Inc.
5 · R.T. Vanderbilt · Co. Inc.
6 · Vermont Talc Inc.
7 · Windsor Minerals Inc.
8 · Eastern Magnesia Talc Co.
9 · Cyprus Industrial Minerals Co.
10 · Southern Clay Products Inc.
11 · Pioneer Talc Co.
12 · Westex Minerals Co.
13 · Pfizer Inc.

tion. Rated capacity is about 80,000 tonnes per annum.

Texas

Four companies produce talc from Hudspeth County in western Texas: Cyprus Industrial Minerals Company, Southern Clay Products Inc., Pioneer Talc Company and Westex Minerals Co. Deposits are large tabular masses of talc in Precambrian cherty dolomite; impurities include chert, carbonate and organic material. Crude talc is often dark coloured due to high carbon content, but the carbon is readily burned off to produce a fairly white product. Nevertheless, Texas talcs are generally off-white, have a high magnesia content, high density, and low absorptive capacity (Kline 1978, p. 309). They are used principally in the manufacture of ceramic wall tiles.

Montana

Montana talcs are of high purity, excellent whiteness and are free of asbestiform minerals; large deposits are found in thick Precambrian dolomite. Montana talcs are the leading talcs for superior filler applications in the United States. Pfizer Inc. and Cyprus Industrial Minerals are the two principal producers. Paint, pulp, paper, plastics, ceramics and cosmetics are the major markets.

Pfizer Inc., Minerals, Pigments and Metals Division, operates a deep quarry in the Rocky Mountains of southwest Montana. The deposit consists of nearly pure talc in a tabular body more than 300 m long and 35 m wide in dolomitic marble. The talc ranges from massive steatite to flaky schistose talc, and in colour from white to pale green. A plant at Barratts, near Dillon, 48 km from the mine employs dry grinding with minimum beneficiation to produce a large variety of grades particularly for the paint, pulp and ceramic industries.

Cyprus Industrial Minerals Company operates talc quarries at Cameron and Alder, and a dry processing plant at Three Forks in southwest Montana. Major production is from the Cameron mine and the Three Forks plant, where an ultra-fine talc product has proved particularly suitable for pitch control in the pulp and paper industry. Productive capacity at this facility is 125,000 tonnes per annum.

California

California talcs are slightly brighter, higher in calcium and more abrasive than Montana talcs, and may contain minor amounts of tremolite (Kline 1978, p. 309). Deposits occur in Precambrian dolomitic marbles. The principal mines are in Death Valley in southeastern California. They are increasingly subject to strong environmental pressures. Cyprus and Pfizer are the major producers.

In 1971 Cyprus Industrial Minerals Company was operating six underground mines in the Death Valley area. Those to the north and west were very pure, of cosmetic and steatite quality, while those from the south and east contained significant amounts of dolomite, calcite and tremolite, and were marketed mainly for paint, paper and ceramics. Underground mining of the rather small irregular talc lenses was generally done by square set timbered stopes (Mulryan 1971, p. 45).

Cyprus now has a single dry processing plant in California at Los Angeles. It produces a range of fine and super fine products, and has a rated capacity of 25,000 tonnes per annum.

Pfizer Inc. also operates underground mines in Death Valley with a processing plant at Victorville. In 1981 Pfizer purchased the Grantham Mine from Continental Minerals, and plans to operate it from surface as well as underground.

Mining Methods

Talc is mined by both underground and surface methods. About three-quarters of North American production is by quarrying, although underground mining predominates in the eastern United States.

With few exceptions talc mining operations are generally relatively small and not highly mechanized. Mining is usually selective, and hand sorting is often employed after primary crushing.

Underground mining methods range from conventional shrinkage stoping to room-and-pillar; timbering is often necessary in soft platy talc deposits. Open pit mines utilize conventional stripping, loading and haulage equipment.

In Canada, underground mining methods are employed by Canada Talc Industries Limited at Madoc, Ontario, and by Bakertalc Inc. in Quebec. Open-pit quarry methods are employed by Steetley Industries (Canada) Limited near Timmins, Ontario, and by Talc BSQ Inc. in Quebec. Pyrophyllite is quarried at the Foxtrap Mine in Newfoundland.

In the eastern United States talc is mined underground in the states of New York and Vermont. R.T. Vanderbilt uses an open stope mining method; access to the underground workings is by a vertical 330 m shaft. The Gouverneur mine is the largest underground talc mine in the United States. Englehard (Eastern Magnesia Talc Company) gains access to its underground mine near Johnson, Vermont, by a 45° inclined shaft. The mine is worked by shrinkage stoping at depths in excess of 300 m below surface. A modified form of shrinkage stoping is also used in Vermont Talc's shallow underground workings at Windham. The mine is less than 30 m below surface.

Talc is mined by both surface and underground methods in California. Talc mines in Texas and Montana are open-pit operations.

Processing Technology

Talc is processed by a variety of

methods, ranging from simple dry grinding to complex mineral separation techniques such as froth flotation (Figure 27).

Process requirements are a direct reflection of raw material quality and the applications in which the talc is to be used. Some deposits consist of pure talc or soapstone. Others may be talc-dolomite, talc-magnesite, talc-tremolite or mixtures of talc with dolomite, magnesite and chlorite. To produce high quality filler products from these mixtures requires separation of the talc from the associated gangue minerals.

The instances where the deposit consists of talc-dolomite or talc-tremolite mixtures, the crude material can be ground as mined, without separating the mineral components. Talc-dolomite and talc-tremolite mixtures are successfully used in ceramics, paints and plastics.

Deposits of nearly pure talc may only require hand or electronic sorting to grade the material or to remove minor waste rock. Grading of talc by sorting facilitates production of talc products with a range of brightness values tailored to specific product applications.

Talc-magnesite or talc-dolomite-magnesite mixtures are processed by the froth flotation process. Because of its natural tendency to float, it is customary to float the talc from the gangue minerals.

High Purity Talc

Pure talc rock is normally soft and easy to crush; jaw crushers or impact crushers are used. The crushed rock is screened and the over-size is crushed in a secondary crusher. This can be an impact or cone crusher, operated in closed circuit with screens. At this stage the crushed rock must be dried if further dry grinding is to be employed.

Because of its inherent softness (No. 1 on the Mohs scale of hardness) talc is easily reduced to its natural grain size. However, physical properties such as its flaky particle shape and its tendency to stick and to act as a lubricant can cause talc to be a difficult mineral to grind by conventional equipment such as ball or pebble mills. Roller or high speed hammer mills equipped with internal classifiers are often used to grind pure talc. Roller mills are effective in reducing talc from 5 cm to 325 mesh (44 microns). This type of mill is frequently used as a pre-grind mill before micronizing, or for the production of coarse and medium talc products.

High speed hammer or pin mills are well suited for grinding pure talc from minus 1cm to very fine sizes. These types of mills are usually equipped with internal whizzer classifiers, which control the fineness of grind. High speed mills are used to produce products with a top size ranging from 45 to 25 microns.

To produce superfine grades of talc (20 microns or finer) requires micronizing. This in effect means the delamination of talc plates and subsequent reduction in the size of the talc particles without destroying the plate-like structure. The process is analogous to the separation of a new deck of playing cards with the cards lightly stuck to each other, followed by breaking the separated cards into similar pieces without destroying the original playing card shape.

High speed hammer mills accomplish this to a certain degree, and it is therefore possible to produce superfine micronized products by air classifying the milled products. Another micronizing process frequently employed in talc processing is a process called "jet milling" or "fluid energy grinding". In this process the talc is ground in specially constructed mills shaped like doughnuts. Hot compressed air or superheated steam is used as the medium for grinding. The talc is fed to the mill by way of a venturi type feed opening and accelerated to supersonic speed inside the mill by the hot air or steam. Particle to particle collision and impact against the mill walls cause delamination and breakage of the talc plates. Centrifugal action in the mill forces the coarse particles to follow a trajectory along the outside circumference of the mill, allowing superfine particles of low mass to leave the mill by way of an outlet located on the inside of the mill. The product is collected by high efficiency cyclones. This grinding method, while effective, is extremely energy intensive.

Vibratory milling and the newly developed agitator mills are considered potential alternatives for micronizing talc.

The combination of high speed hammer or pin mills operated in closed circuit with high efficiency air classifiers is considered a promising method for the production of very fine talc fillers. It is expected that high efficiency classifiers will be more extensively used in talc micronizing as a means of improving the effectiveness of the micronizing process.

Mixed Talc Deposits

Mixed deposits, such as talc-magnesite, are processed differently from those which are essentially pure talc. Following primary and secondary crushing, the rock is ground in ball or roller mills to the particle size at which the talc particles are liberated from the other minerals. Ball milling can be wet or dry. For dry grinding, the rock must first be dried to a low moisture content.

Separation of the talc from the associated minerals may be accomplished by froth flotation or by the use of gravity separating tables. Froth flotation is the process most commonly used. The ground material is conditioned with the appropriate flotation reagents and the pH of the slurry adjusted to the required level. The talc is then floated in a series of rougher cells. This produces a bulk concentrate

CONCEPTUAL FLOWSHEET – TALC FILLER PRODUCTS
DRY OR WET PROCESSING ALTERNATIVES

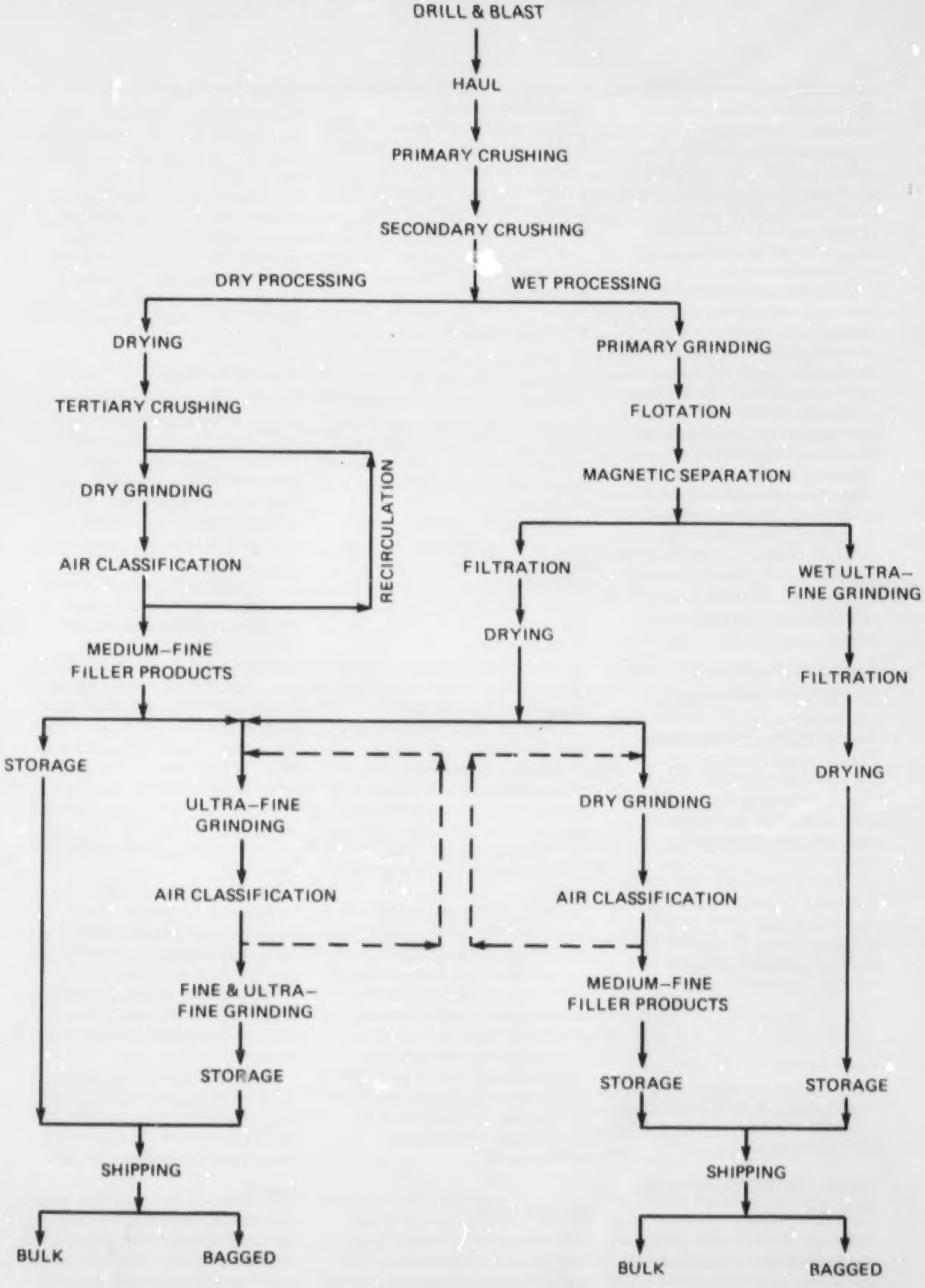


FIGURE 27

containing most of the contained talc and some of the gangue minerals. The talc concentrate is then refloated in a series of so-called cleaner cells, to obtain a higher purity concentrate. It may be necessary to repeat the cleaner flotation step several times in order to achieve maximum product purity.

Magnetic separation of the flotation concentrate may be necessary to remove magnetic or paramagnetic minerals. This will improve the purity of the product and enhance its brightness.

The talc concentrate is thickened using conventional or lamella type thickeners. Thickened concentrate is then filtered using vacuum or pressure filters. Filter cake is dried using fluid bed, flash or belt driers. The dried concentrate, depending on its particle size, can then be further processed, using the micronizing techniques used for pure talcs.

Surface Treatment

Like other mineral fillers, the properties of talc can be enhanced by surface treatment. This is of particular interest for the application of talc fillers in plastics. Surface treatment may consist of coating with metal stearates, or with coupling agents.

Coating of mineral fillers with stearates or coupling agents is a specialized and often proprietary technology developed by the filler producer or by companies specializing in filler treatment.

High intensity mixers of the semi-batch type, such as the Henschel Mixer, are used in Europe. High speed pin mills, vibro-energy mills, or continuous high intensity mixers may be used for surface treatment.

Uses, Specifications, Prices

Talc products are used as fillers in a wide range of industrial applications. Talc is also used in such non filler applications as talcum powders, cosmetics, ceramics and rubber.

The most significant attributes of talc fillers that determine their commercial usefulness are:

1. Particle size (i.e. fineness).
2. Whiteness or brightness.
3. Mineralogical and chemical purity.
4. Low abrasiveness.
5. Softness

Particle Size

Talc filler products are produced in a wide range of sizes, from 100 mesh to 10 microns and finer. Most talc producers offer a full range of products, with each product designed to meet the requirements of a particular industrial application.

Specifications for talc products used in paints are covered in A.S.T.M. (American Society for Testing Materials) specifications D-605-69, MIL-P-15173, A & B, as issued by the Navy Department of the U.S. Government and 52-MA-523 issued by the Maritime Administration of the United States Department of Commerce. There are no comparable Canadian product standards for talc fillers.

In general, specifications are agreed upon between the buyer and seller and are usually based on ''typical product'' specifications as issued by the talc filler producer.

The particle size distribution of talc fillers is controlled by the grinding and classification process. Brightness and mineralogical purity are achieved by purification or concentration processes such as froth flotation, magnetic separation or acid leaching. The oil absorption of talc fillers is a function of particle size; the oil absorption increasing with decreasing particle size.

Brightness

Requirements for brightness and purity are particularly high in paints, plastics, paper, health care and cosmetic products.

Mineralogical Purity

Mineralogical purity is of great importance in applications such as plastics, paper and in health care and cosmetic products. While talc is a very soft mineral, some of the minerals often associated with talc are abrasive or soluble in acidic environments. This will eliminate their use in paper or cosmetic products, unless beneficiated to remove these contaminants.

Abrasiveness

There are several methods to measure the abrasion value of talc products. The paper industry uses the so-called Valley Abrasion method as the standard method for determining the abrasiveness of talc or other minerals used in the paper making process.

The most critical applications for talc are in the health care products field such as talcum powder. Talc products to be used in those applications must be of the highest purity, brightness, absolutely free of abrasive components and must be biologically inert. Health care and cosmetic products are not truly filler or extender applications. They are only mentioned here for the purpose of identifying other major industrial applications for talc products.

Another major non-filler use for talc is in ceramics. Talc is used in a number of ceramic compositions, such as wall tile and slip casting bodies.

Pure talc is also used in the production of the catalyst support used in automotive exhaust systems.

Other minor non-filler applications are as a dusting or releasing compound in rubber moulds, and as an anti-sticking dusting compound for roofing shingles.

Paint

Talc products are extensively used in paint as a pigment extender. Talc provides good thixotropic properties to paint and is also excellent for the control of

Table 49 Filler Applications for Talc

Application	Function	General Specification
Paints	Used to provide "body" to paint. Provides good viscosity and is excellent for control of gloss in interior and exterior semi-gloss and flat paints. Greatest use is in exterior paints. Also used in traffic paints and low gloss industrial finishes.	High brightness. Controlled particle size. Chemical purity. Pure talc–tremolite (prismatic) grades are used. Both fibrous and platy talcs are used in paint.
Plastics	Primary use is in polypropylene, polyester and polyethylene. Provides stiffness, good heat deflection, thermal stability and excellent dimensional stability.	High brightness. Fine particle size. Coating with metal stearates improves performance in some applications. Fibrous talcs tend to provide greater reinforcement.
Paper	As pitch adsorbant in pulp and paper manufacturing. Minor use as paper filler.	Fine particle size. High surface area. High brightness. Low abrasion and high pitch adsorption efficiency is required. Only talcs with platy structures are used. Must be low in acid solubles.
Putty, Caulks and Sealants	In putty and caulks to provide good thixotropic properties as a reinforcing filler and to provide sag control. Used extensively in polyester automotive body fillers.	Lower quality talcs can be used. Good brightness required. Coarser grades with lower oil absorption are used.
Jointing Compounds	As replacement for asbestos. Provides reinforcing properties. Provides good thixotropy and sag control on vertical surfaces.	Medium brightness. Lower quality, low cost coarser platy and fibrous talcs are used.
Adhesives	Used to provide resistance to chemical attack. Also used in ceramic tile adhesives.	Lower grades. Medium-fine to fine grades are used.
Rubber	As mould release and dusting compound.	Lower quality, coarse fillers. Platy talcs are most commonly used.
	Other Talc Uses	
Asphalt Roofing and other materials	Used as a dusting compound to prevent sticking.	Lower quality, coarse grades are commonly used.
Cosmetics	Used in cosmetic powders as the main ingredient.	High quality, very pure talcs. Must be biologically inert and have a high fragrance retention. Only soft talcs with good lubricity are used.
Health Care Products	Used in talcum powders.	Only very pure, soft, talcs are used. Must be biologically inert. Good lubricity (slip) is essential. This is a very critical talc application.

gloss and sheen. Platy talcs improve enamel hold-out and brushability. Fibrous talcs reduce cracking in exterior paints. Talc is used in conjunction with other fillers and extenders in main paint formulations.

Talcs are used in such paint formulations as alkyd semi-gloss, exterior low lustre acrylic flat paints and in concrete block filler paints. Talc provides a high degree of sheen uniformity and is an excellent viscosity control pigment.

Talc is also used in industrial paint finishes, such as office furniture to control sheen.

The properties that talc extenders contribute to a paint are well defined. It is therefore not difficult to evaluate a new talc pigment extender.

The evaluation starts with checking the physical properties of the talc extender such as particle size, Hegman reading, brightness, oil absorption, dispersability, water solubility and the pH. Once satisfied that the new talc product has similar physical properties to those in current use a paint formulation incorporating the new talc product is prepared and compared.

The following properties are of particular concern:

Viscosity at a specified pigment to vehicle ratio, and the effect of time on viscosity and stability.
Settling resistance.
Shelf life.
Effect of freeze-thaw on viscosity.
Ease of dispersion.
Brushability.

Test panels will then be prepared to test the properties of the paint film, such as: -

Sheen uniformity.
Gloss.
Scrubability.

The paint prepared with the new talc product should exhibit similar or superior properties to the paint containing the standard talc extender. It is customary for paint manufacturers to purchase talc extenders from several producers, and it is therefore important for a new talc product to be compatible with others so it can be used interchangeably.

Other than performance criteria, the overall economics and product availability are important. The delivered cost of the extender must be competitive with competing products of equal quality.

Product uniformity from shipment to shipment is critical. The paint manufacturer depends on this uniformity to assure constant quality of its products.

Typical products used by the paint industry have top particle sizes ranging from 45 to 20 microns with a Hegman rating of 4 or 5. Very fine 10 micron "top-size" grades with a Hegman rating of 6 are used in industrial paint formulations for gloss control.

The amount of talc added to a paint is dependent on the type of paint. Addition levels of less than 0.1 kg to 0.3 kg per litre are used.

Prices
The paint industry uses a wide range of talc products. The more popular grades of talc are quoted at prices ranging from U.S. $100 to $200 per tonne in 22.7kg (50 lb) multiwall paper bags f.o.b. producers plant.

Plastics

In plastics, talc is considered a reinforcing filler. Polypropylene is the polymer in which talc is used to good advantage. It improves tensile, compressive and flexural strength; it also imparts good dimensional stability and improves the heat deflection temperature. As with most mineral fillers, surface coating with metal stearates or functional coupling agents improves the performance of the treated filler.

Talc, one of the softest minerals, is the least abrasive natural mineral filler used in plastics.

Talc fillers are available in a range of particle sizes and purity. For plastics, talcs with an average particle size from 3 to 8 microns are most commonly used. Finer grades with average particle sizes of 1 micron are used in applications where higher impact strength is desired.

Because of the high flexural strength and good heat deflection temperatures of talc-filled polypropylene, it is used extensively in "under the hood" automotive applications. Talc fillers are also used in the appliance industry in such products as refrigerator linings and washing machine agitators.

Talc fillers are used in high density, high molecular weight polyethylene to improve impact strength; also in polystyrene, nylons and other engineering plastics.

In general, talc fillers contribute higher strength, stiffness and dimensional stability to plastics.

Finer particle size, modified particle distributions, surface coating and higher flake aspect ratios are some of the areas of research and development that may further the use of talc fillers in plastics. As the understanding of particle physics expands, the reinforcing properties of talc are likely to be improved, achieving greater strengths at higher loadings. Surface treatment with stearates or coupling agents is expected to grow as the benefits of such treatment become more evident.

Loading levels of talc in polypropylene range from 20 to 40 percent. In other polymer systems the level may range from 5 to 15 percent.

Prices
A wide range of talc products is used in plastics. The most popular grades are quoted in the range U.S. $90 to $200 per tonne in 22.7kg (50 lb) multi-wall paper bags f.o.b. producer's plant.

Paper

Talc is a mineral with natural hydrophobicity; pure talc particles exhibit a low affinity for water and are difficult to wet. In contrast, talc has a high affinity for organic substances. Talc will therefore act as a scavenger for organic substances present in aqueous systems. This is due to the fact that the planar surfaces of talc are electrically neutral, hydrophobic and thus strongly organophillic.

This phenomenum is amply demonstrated in the pulp and paper industry where talc is used as a pitch adsorbant. Pitch is a natural constituent of most pulp wood. The pulping process liberates the pitch, essentially a fatty resin, which will form a sticky agglomerated mass, fouling the processing equipment if not removed or neutralized. Pitch may also evidence itself as emulsified resinous soaps formed during pulping operations.

Pitch is detrimental in the paper sheet-making process because it results in sheet breaks, pinholing and poor sheet formation. It also causes plugging of the Fourdrinier wires contributing to increased wear and downtime.

Finely ground, pure, platy talcs will selectively adsorb the pitch, coat and disperse it, thereby preventing it from depositing on equipment or causing paper defects.

In addition to pitch control, a high percentage of the talc is retained in the paper fibre, in effect acting as a filler. Talc fillers are much less costly than wood pulp, and as a result talc not only reduces pitch problems but also reduces the amount of pulp necessary, and hence the cost of the paper.

Talc products for pitch adsorption must be of very fine particle size, good brightness and have a low abrasion value. Only platy talcs are effective. Fine talcs, with a 10 micron top size, high surface area and good platy structure are the most effective. It is used in the form of dry powder or pellets, dispersed in water and added to the pulping or paper-making process.

The amount of talc added is dependent on the amount of pitch encountered in the process, which is a function of the type of pulpwood used. Addition levels may be as low as 5 kg or as high as 20 kg per tonne of pulp.

Paper Filling

In North America only small amounts of talc are used as paper filler. In contrast, the Scandinavian countries and in particular Finland use talc fillers extensively. Excellent availability of high quality talcs in Finland and a very well developed, technically strong pulp and paper industry have combined to develop the use of talc as a paper filler, substituting for kaolin filler clays. The Scandinavian countries have no indigenous kaolin resources and high cost of imported kaolin products spurred the development of talc as a paper filler. Finland has several large talc producers, concentrating on products for the pulp and paper industries in Scandinavian and East European countries.

Paper Coating

Talc has long been considered a potential paper coating material. Research, particularly by paper and talc producers in Finland indicate that talc can be used as a paper coating pigment. One of the most difficult problems to be overcome is the dispersion of talc in aqueous systems at high solids, while maintaining good slurry viscosity, solution rheology and stability. These difficulties can be resolved (Eklund and Tierfolk 1981).

The use of talc for paper filling or coating is unlikely to proceed at a high pace in the United States because excellent availability of kaolin clays minimizes the need for developing substitutes. The use of talc as a paper filler is likely to advance in countries which have no kaolin resources and where talc products are readily available at lower cost than imported kaolin.

Conversion to the alkaline sizing process by the paper industry may also advance the use of talc as a paper filler at locations where talc fillers are available at a cost competitive with other fillers such as very finely ground calcium carbonates.

Prices

Talc used as a pitch adsorbant is marketed as a powder or in granulated or pelletized form. The granulated or pelletized forms have higher bulk densities, allowing better utilization of transportation and storage facilities; they are also more readily dispersed.

Prices for pitch adsorbing grades of talc shipped in bulk are quoted at U.S. $180 per tonne, f.o.b. producer's plant.

Putty, Caulks, Sealants

Talc finds only limited application in putty. It is used extensively in automotive "body patch" compounds, where it is used in a polyester base. Both fibrous and platy talcs can be used, providing reinforcement, anti-cracking and excellent sanding properties. The talc should be relatively free of calcium carbonate as this may affect the storage stability of the uncatalyzed compound.

In caulks and sealants, talc provides good reinforcing and thixotropic properties. Fibrous talcs tend to provide better reinforcing, flow and anti-cracking properties; platy talcs tend to enhance the thixotropic properties. Talc has replaced asbestos in these applications to a large extent.

Most talcs have a high oil absorption which tends to prevent resins from migrating to the surface where they would otherwise make a poor contact with the caulk or sealant.

Medium and fine grades of talc are used in caulks and sealants. Color, while important, is not always critical. Grades of lower purity containing dolomite, prismatic tremolite or other minerals typically associated with talcs can be tolerated to some degree. Talc is second to ground calcium carbonate as the most common mineral filler used in caulks and sealants.

Up to 20 percent talc may be used in caulks; typical levels are 10 to 15 percent. In sealants talc is used at levels from 5 to 10 percent.

Prices

Prices for the talc grades most commonly used range from U.S. $65.00 to $110.00 per tonne in 22.7kg (50 lb) multi-wall paper bags f.o.b. producer's plant.

Jointing Compounds

Talc, like calcium carbonate, is used in the production of jointing compounds for dry wall construction to fill cracks and other imperfections. In this application talc provides good reinforcing, anti-cracking, trowelling and flow properties. Fibrous talcs are preferred over platy talcs, offering better overall properties usually at lower cost.

Jointing compounds are very heavily loaded with mineral fillers, reaching levels up to 80 percent. Talc is a secondary filler, usually in combination with ground calcium carbonate. Talc addition may be as high as 15 percent of the total filler content.

Medium-fine to coarse grades can be used in jointing compounds. Brightness is not critical but in general good colour is desirable. Talcs containing minor amounts of other mineral constituents can be used. Talc containing calcium carbonate, dolomite or prismatic tremolite may have a performance advantage over pure talcs because of a combination of desirable properties. However, cost is usually the deciding factor.

Prices

Talc used in jointing compounds is in the lower price category. Cost is a critical consideration. Talc fillers used in jointing compounds are marketed at U.S. $60.00 to $80.00 per tonne, in 22.7 kg (50 lb.) paper bags, f.o.b. producer plant.

Rubber

Talc finds only limited use as a filler in rubber. Its typical use is as a dusting or anti-sticking agent and as a mold release compound.

Talc has excellent anti-sticking properties and is used to dust "in process" rubber slabs or parts to keep them from sticking. It is also used to dust the rubber molds so the parts will separate easily from the mold. Platy talcs are preferred in this application.

The use of talc in rubber is a minor application. Minus 200 mesh (74 microns) or medium-fine minus 325 mesh (44 microns) grades are used in these applications.

European research (unpublished) reports that superfine talcs with an average particle size of less than 0.5 micron exhibits reinforcing properties in rubber. The technology for grinding talc to this particle size has not been developed to the commercial level.

Talc is used in rubber-based adhesives as discussed in the section on adhesives.

Adhesives

Platy talcs are used in rubber-based vinyl and ceramic tile adhesives. They are also used in electrical insulating tape.

In adhesives, as in other applications, talc is used to lower the cost of the product without adversely affecting its properties. In some instances the use of talc will improve the properties of the product. Talc fillers are noted for improving the moisture, chemical and acid resistance of adhesives.

Talc is used in epoxy, butyl and natural rubber-based adhesives. Grades ranging from 98 percent finer than 325 mesh (44 microns) to 100 percent finer than 15 microns are used in these applications.

Talc fillers may be loaded up to 35 percent in epoxy-type adhesives; in butyl-based adhesives loading may vary from 15 to 25 percent. In natural rubber-based adhesives talc addition is low, usually less than 5 percent.

Price

Talc fillers used in adhesives cover a wide range of particle sizes. Platy talcs are prefered. Cost of the talc fillers is not an overriding consideration. Performance is the main criteria. Prices may range from a low of U.S. $75.00 to a high of U.S. $185.00 per tonne in 22.7kg (50 lb.) multiwall paper bags.

Asphaltics

Talc is used as a dusting or anti-sticking powder in asphaltic roofing products such as rolled roofing or shingles.

Platy talcs of coarse particle size (40 mesh) are most commonly used in this application. Grades containing dolomite or calcium carbonate can be used providing their performance characteristics are satisfactory.

This is not a filler application. Talc grades used in asphaltics are usually of lower quality and cost. Application level is approximately 0.25 kg per 45 kg of asphaltic roofing product.

Price

Talcs used in roofing applications are usually low cost products. Products marketed in 22.7 kg (50 lb.) paper bags range from U.S. $60 to $80 per tonne. Mica is a suitable substitute for talc in this application.

Cosmetics

Talc is the main ingredient of cosmetic powders. For this application only the purest platy talcs, free of abrasive minerals are used. Colour, softness and fragrance retention are the most important product considerations. Cosmetic talcs must also be biologically inert, requiring special treatment during processing, handling and packaging. Treatment with super-heated steam usually destroys any biological activity. To prevent contamination the products must be packaged immediately following processing, with special precautions taken during handling.

Cosmetic grade talcs are usually produced by the froth flotation process in order to achieve the required purity. Particle size of cosmetic talcs is in the medium-coarse range, 80 to 90 percent finer than 325 mesh (44 microns).

Talcs for cosmetic applications are extensively tested by the producer of cosmetic products. This testing program is costly and time consuming. Therefore, unless there is a significant economic advantage, the cosmetic product producer will tend to stay with a "time proven" product. Cosmetic talcs are covered by C.T.F.A. and United States Pharmaceutical specifications.

Prices

Because of the special treatment and care required in the production of cosmetic grade talcs, prices for suitable products range from U.S. $150 to $200 per tonne and higher.

Health Care Products

Talc is the main component in health care products such as baby powders. This is a very critical application; only the very pure talcs can be used and then only after extensive testing.

High purity, colour, softness or slip are the main product criteria. The talc must be free of any abrasive or other harsh minerals. Talc used in health care products must be biologically inert and must remain so indefinitely during storage.

Great care must be taken during production and the talc must be sterilized with steam before packaging. Products must be packaged immediately following production to avoid any contamination.

The testing of talc for use in health care products is very costly and time consuming; only very high purity talcs can be considered.

In North America, talcs used in health care products are produced by the froth flotation process and are handled under strictly controlled conditions. Its use is characterized by the uncompromising quality standards demanded by this industry. Very few talc products can comply with these stringent requirements. Product cost, while important, is secondary to quality.

Prices

Talc products used in health care products are marketed at comparatively high prices, ranging from U.S. $200 to $400 per tonne in 22.7 kg (50 lb.) bags. Some talcs for health care products are imported from Italy and France.

Ceramics

Talc is used extensively in the production of ceramic products. In fact the ceramic industry is the largest commercial consumer of talc products.

Talc is used primarily in ceramic compositions with low maturing temperatures or as an auxiliary flux.

Talc is an essential and important ingredient in ceramic wall tile. It has a high thermal expansion and low moisture expansion allowing rapid firing cycles of the tile without crazing of the glaze. Coarser, 100 and 200 mesh talcs are used in the production of wall tile.

Finer ground, 325 and 400 mesh talcs find their major use in "vitreous" ceramics such as dinnerware and porcelain. In these applications talc can substitute for up to 20 percent of the nepheline syenite or feldspar. This allows lower maturing temperatures, with resulting fuel savings.

Eastern talcs, particularly the talc-tremolite types, are used extensively in these applications.

Talc is also used as an auxiliary flux in vitreous ceramics such as high alumina, electrical porcelain, sanitary ware and artware. It is used in combination with either feldspar or nepheline syenite with which it forms an eutectic. This results in tighter and stronger ceramic bodies at normal firing temperatures, or in products of normal strength at lower firing temperatures.

Talc is also used in high temperature, low thermal expansion ceramics, commonly referred to as cordierite–type bodies. Talc is used for instance in the catalyst supports for automotive catalytic converters. Talcs used in this application must be low in iron and carbonate.

The use of talc in ceramics is expected to grow based on its ability to reduce firing temperatures and promote faster firing. Talc may also play a role in the production of the so-called "silica free" body compositions that are being developed.

Talcs used in ceramics must be white-firing particularly for use in semi-vitreous or vitreous ceramics. For high temperature–low thermal expansion the talc should be low in calcium and magnesium carbonates.

The particle sizes of talcs used in ceramics range from 100 mesh to 400 mesh. Particle size influences the maturing temperature, its fluxing action and thermal expansion.

Before talc products can be used in ceramic compositions, their properties must be well defined so that the ceramic technologist or engineer can predict their performance in specific applications.

Production

World production of talc has increased from about 3.2 million tonnes in 1972 to 4.6 million tonnes in 1981. However, except for the advent of Steetley production on the Canadian scene in 1979, growth in talc production in the United States and Canada has been minimal over the period 1977-1981 (Table 50). Production in the United States is summarized by Dickson (1982, p. 75) as follows:

> The major producing states in the U.S.A. are Montana, Texas, New York, Vermont, and California–in that order in 1981. In 1978 Vermont was the leading producer. The top four represent about 80% of total U.S. production and total output from each one was in the range of 175,000–330,000 tpa in 1981. Montana produced 324,000 tons, Texas 282,000 tons and the other two leading producers are now included in the "others" category of 496,000 tons to prevent disclosure of company confidential data. If California, with an output of 111,000 tons in 1981, is included with the top four states this represents about 90% of the U.S. production.
>
> The market patterns for each of the major producing states differs because of grades and locations. In each case a large

proportion of the output is consumed in the geographic area where it is produced–Texas (and Georgia) supplying the South, Montana and California supplying the West and New York and Vermont covering the Northeast. The cost of transport plays an important part in the delivered cost of many grades that can sell for as little as $40 per ton. However, there is sufficient diversity of grades and types of talc that substantial amounts of the higher priced, higher quality talcs are transported long distances and about 300,000 tpa are exported, mainly to Canada and Mexico, but also to Europe, Japan, and other overseas countries.

In Canada, the value and volume of talc shipments increased substantially in 1979 (Table 50) as a result of renewed production at Timmins by Steetley Talc Limited. Production of pyrophyllite in Newfoundland was entirely exported for use in ceramic tile.

Available statistics on consumption of talc in Canada are shown in Table 51.

In the United States in 1981, talc was produced at 35 mines in 11 states. California had the most mines (12) but major production was from Montana, Texas, New York and Vermont. Consumption of talc (excluding pyrophyllite) in 1981 was 38 percent in ceramics, 21 percent in paint, 11 percent in plastics, 9 percent in paper, 8 percent in cosmetics, 4 percent in rubber, 3 percent in roofing, 1 percent in insecticides and 5 percent in other uses (Clifton 1982).

United States exports of talc to Canada have been increasing steadily in recent years, and in 1981 were about 72,000 tonnes valued at U.S. $4,632,000. Imports of ground talc from Canada are also increasing: In 1980 they were 3,409 tonnes valued at U.S. $385,000, and in 1981 they were 6,278 tonnes valued at U.S. $882,000 (Clifton 1982). This trend is expected to continue.

Table 50 Annual Talc Production

	Tonnes		
	Canada	United States	World
1977	72,400	1,099,000	3,736,200
1978	61,661	1,268,000	4,121,125
1979	90,330	1,268,000	4,383,050
1980	92,000	1,127,000	4,548,200
1981	89,000	1,236,000	4,600,000 (est.)

Source: Industrial Minerals, December 1982, p. 59; revised from Clifton 1982, p. 1.

Table 51 Canadian Consumption of Talc

	Tonnes	
	1969	1979 (est.)
Paint and varnish	6,317	10,143
Gypsum products		7,680
Roofing products	6,768	7,442
Pulp and paper	3,779	7,311
Ceramic products	8,952	5,864
Toilet preparations	837	701
Chemicals		1,027
Rubber	1,546	2,600
Insecticides	651	
Cleaning compounds	592	
Pharmaceutical products	272	
Linoleum and tile	104	
Chemicals, gypsum prod., etc.	4,442	
Adhesives, floor covering, insecticide, etc.		4,172
	34,261	46,940

Source: Côté 1971, Boyd 1981.

Table 52 Estimated Annual Talc Filler Market, 1980-1985

	Total Canada and United States	Study Area
	Tonnes	
Paint	130,000	90,000
Paper	75,000	55,000
Putty, caulks, sealants	61,000	36,000
Plastics	42,000	28,000
Rubber	30,000	12,000
Adhesives	4,000	2,000
	342,000	223,000

The estimated market for talc filler is summarized in Table 52.

Competitive Materials

The strongest competition for talc in plastics, paint, and putty, caulks and sealants is calcium carbonate. Better colour, lower oil absorption and lower cost are attractive features of finely ground calcium carbonates from white marble deposits of high purity.

Mica appears likely to become a major competitor in plastics because of its reinforcing properties. It also replaces talc in paints where vapour resistance is desirable, and may also replace it in roofing materials.

Diatomite is sometimes used instead of talc in flatting applications.

Kaolin may be substituted for talc in interior paints.

Pyrophyllite, feldspar, wollastonite and nepheline syenite compete with talc in certain ceramic applications.

Certain talcs in the United States have attracted unfavourable environmental concerns. In California these are primarily of an aesthetic concern in delicate natural areas, threatening the continued existence of talc mining in the important Death Valley area. Tremolitic talcs in the East are under heavy regulatory pressure because of suspected health hazards. The combined effect of these concerns is to focus consumer attention on alternative materials, which may therefore experience levels of substitution in excess of historical trends.

Trends

Talc production in Ontario and Quebec has been significantly improved in recent years as a result of changes in ownership or company reorganizations. Enlarged and improved processing facilities have been completed or are plannned at all four locations.

Steetley Talc has been successful in competing with Montana sources for pitch control in the paper market of the Northeast, and increased growth for Steetley in this market seems likely because of the transportation advantage. Steetley is also marketing a cosmetic grade.

Canada Talc, under new ownership, has been successful in developing substantial new reserves. Planned expansion and improved processing seems likely to put this company into a better position in certain high grade talc markets.

In the United States, talc production from the eastern states has been steadily declining since the early 1970's when government regulatory agencies began questioning the health hazards of tremolite. Western producers, particularly in Montana, have experienced a healthy growth rate during the same period by virtue of talc products free of asbestiform minerals. These trends have levelled off in recent years, and action by R.T. Vanderbilt towards proving that its tremolite is a non-fibrous variety, and hence not a health hazard has improved the market for Eastern talcs.

Production from the mines in Death Valley, California, will likely decline in the face of increasing environmental pressures.

Market trends in North America have been summarized as follows (Dickson 1982, p. 75):

> There has been little change in the proportion of the domestically consumed talc in the two major uses–ceramics and paint. The proportion of the total consumption used in ceramics has fallen by 2% to 31% since 1978 and there has been no change in the proportion used in paint. Total consumption for the years 1978 to 1981 shows only minor differences. The use of talc in most other applications has remained steady during this period with the exception of paper and plastic applications. The proportion of talc consumed has increased from 7% to 11% in the case of paper and from 6% to 12% in the case of plastics. The industry is very wary of making predictions of future production and consumption because trends are to a large extent being masked by the effect of the economy on the overall market. Additionally, some of the possible increases in consumption depend on changes in technology particularly in the case of paper, plastics, and ceramics.

He concludes as follows (Dickson 1982, p. 78):

> It would seem unlikely that there will be any major change in the talc industry of North America until the economy recovers. The few trends that are evident suggest that consumption in the paper industry may increase both in pitch control and in filler and coating applications. Ceramic grades may have to fight off competition from wall tile manufacturers using redfiring bodies. In plastics the increased use of plastics in automobiles may prove to be a lucrative market. As far as cosmetic grades are concerned there are indications that competition may be stiff in a few years time. Steetley has already entered the market, Pfizer is manufacturing products using its own talc production, Vermont Talc is planning to produce cosmetic grades in 1983, and there has been reports that Australian cosmetic grade talc will become significant. Another factor in the market that is obviously being taken seriously is that corn starch may replace talc in many of its cosmetic applications like baby powders. There are not even any hints that corn starch is a hazard to health, which is attractive, and Johnson & Johnson are already selling corn starch products alongside their better-known talc baby powder. Obviously the cosmetic market, which is already very competitive, could become even more so in the future. However, until the economy improves change will be slow.

10 Marketing

Introduction

The gathering of reliable market data is one of the most difficult and time consuming undertakings in developing a viable mineral filler project. There are many factors that must be evaluated apart from technical considerations of the mineral resource itself. Normally it is advisable to conduct preliminary market and transportation cost studies prior to embarking on detailed technical evaluations. One can proceed only if a solid market opportunity exists, backed by the knowledge that an acceptable product can be produced from the available resource at a cost that will allow a profit to the producer and a saving to the consumer.

Mineral fillers are noted particularly for the large variety of individual products necessary for the equally large variety of applications in which they are used. A single filler mineral from a single source may be offered in dozens of distinct products, many with specifications tailored specifically to a single application or consumer. Physical characteristics are the most common variants; particle size, shape and size distribution are the usual distinguishing features.

Once established in a particular application, a specific filler product is not easily substituted even by a similar product from another source. Minor differences in mineral or chemical composition may have subtle effects on such characteristics as whiteness, viscosity and oil absorption. Consumers are generally reluctant to change unless product performance is notably improved or costs are substantially reduced.

Industrial mineral producers range from multi-national corporations with a variety of mineral products to small individual producers with a single product line. Consumers may be equally diverse, some purchasing thousands of tonnes per year and others needing only a few bags.

In establishing a marketing system, producers can use either a direct or an indirect sales approach, or a combination of the two, as discussed in the following sections.

Direct Sales

This is the use of company employee salesmen for sales solicitation and sales service backed up with home office staff support. Usually these salesmen are located in the field near a group of potential customers, and have expertise in the consuming industries' technology. Office support staff can include administration, transportation, market research, product and application development, and others.

One major kaolin producer has six offices located across the United States, supervising sales handled on a direct sales basis (as well as sales through 44 distributor sales and warehouse locations).

In general the large producers have separate marketing and sales functions while in smaller organizations the two functions are combined. Companies with only a small product line, selling in high volume to a small group of customers, tend to favour the direct sales approach even if the market is geographically diverse. Producers with a large product line, marketing products for many different industrial applications, usually channel part of their sales efforts through qualified distributors.

Indirect Sales

Indirect sales involve independent distributors, sales agents, brokers and jobbers; either national organizations with multiple office and warehouse locations for extensive sales development or local organizations for intensive sales development in a limited geographic area. Some distributors specialize in specific consuming industries or segments of industries. Most distributors represent a group of non-competing producers, thereby spreading sales costs across a broad base. As an example, a major silica producer in the United States handles sales from its home office through twenty-two distributor and warehouse locations. In addition, many of these silica distributors also handle the products of one of the kaolin producers.

Cost Effectiveness

Some producers use both routes, considering cost and effectiveness. For a limited group of readily identified large consumers, direct sales may be selected, combined with indirect sales to another more dispersed group of consumers. For example, in the first case, the paper industry, in the second case, the paint industry. Also, an industry with concentration in a few companies but dispersed overall, such as fabricated compounded plastics, can be handled on both bases; for example, direct sales to major national consumers and indirect sales to smaller local consumers. As noted previously, the possibilities under only these two routes are exponential, considering multi-mineral producers and consumers who have multi-market structure.

The producer balances his marketing plan to reduce cost and maximize profits. The consumer evaluates suppliers, not only on price but also on quality, service and reliability in fulfilling his needs. In most instances, the mineral filler is one of the lowest cost components of a consumer's finished product but is critical in the product's performance.

For the producer, a direct sales approach gives the highest degree of control, but usually at higher cost than indirect sales. A broad based, multi-mineral producer, or one diversified into several complementary product lines, can justify a direct sales force and possibly local offices, warehouses and transportation equipment. An indirect sales approach gives less control, but at a lower cost.

A distributor or sales agent may provide services that the producer is unable or unwilling to provide, such as:

1. Credit extension beyond normal terms of payment.
2. Delivery from local warehouse of small lots, less than unit load.
3. Billing in local funds, delivered, if an international boundary is crossed in the route from producer to consumer.
4. Local sales service and technical service.

A trend that is expected to continue is the role of the distributor diminishing in favour of the direct sales route by producers.

Paper

Introduction

The paper industry is the largest consumer of fillers. Almost all filler use is concentrated in two segments of the industry: filled and coated printing and converting paper and coated bleached packaging board. Fillers are used primarily to prepare the paper or paperboard for printing by giving an opaque and smooth bright surface.

General stages in the preparation of paper include:

Pulp Mill

Chemical, thermal or mechanical liberation of fiber from wood pulp, possibly bleached.

Fiber Preparation

Mechanical dispersion through beating and refining of the pulp; introduction of fillers such as kaolin and calcium carbonate and process aids such as talc.

Wet Web Formation

Deposition of the fiber slurry (pulp plus water) on a continuous wire, travelling at high speed and dewatered by gravity and vacuum into a coherent wet web.

Drying and Pressing

Passage of the wet web over drying drums with press felts, giving a dried sheet of paper.

Finished Product

Winding of the finished dried paper into jumbo rolls.

Converting and Finishing

Slitting of the jumbo rolls into smaller rolls or sheeting.

Coating pigments such as kaolin and calcium carbonate dispersed in water with a binder can be coated "on machine" after the drying and pressing stage with an additional drying step to dry the coating; or "off machine" on a separate coating unit using finished paper as feed.

Highly filled and coated paper can exceed 10 percent of finished paper weight as filler and 20 percent as coating, or over 30 percent of total finished paper weight. Typical of this loading level would be the printing stock of a fashion magazine filled and coated both sides.

Pulp is a saleable product in itself, for sale to paper companies that do not produce their own pulp or have insufficient pulp making capacity.

Paper and paperboard products can be broadly categorized into four main groups: printing, packaging, specialty and other; excluding pulp, construction paper and paperboard, and items such as roofing felts are eliminated from consideration since they use no filler.

Printing papers can range from newsprint containing no filler, to filled and calendered (pressed and polished) paper used for advertising fliers and catalogues, to filled and coated paper used for magazines and brochures.

Packaging paper and paperboard can range from unbleached brown paper and paperboard (the grocery bag and the shipping carton) utilitizing no filler, to bleached white paper and paperboard used for consumer product packaging which may or may not be coated. Specialty paper and paperboard include playing cards that may use barite as a weighting agent, wallpaper that may use mica for a decorative glitter effect, cigarette paper that uses high levels of carbonate filler to control burn rate and many others. However, mineral use in these specialty applications is negligible compared with the volume of fillers consumed in the paper industry as a whole.

Other uses include tissues and towelling, spiral wound tubes, containers and drums (such as frozen citrus juice containers and automotive lubricating oil containers) and corrugating media. Included also are tags, labels, file folders and business forms.

Converters who purchase paper or paperboard may apply the finished filler coat to such items as labels, tags, boxes and bags.

The United States and Canada produce over 50 percent of the world's pulp, the base fiber from which paper and paperboard is made, and 45 percent of the world's paper and paperboard (Busch 1980). Canada is the world's leading producer of newsprint with 37 percent of the world's production (Turner 1980); but newsprint uses little or no filler. Hence the large newsprint producers of northeastern Ontario are not potential markets for Ontario's nearby kaolin resources as is often erroneously believed.

Except for small tonnages of talc used as a process aid in pitch control and the mineral use in specialty papers previously mentioned, major segments of the paper industry use no fillers at all, including:

Newsprint
Pulp
Tissues
Towelling
Tubes, containers, drums
Construction paper
Unbleached packaging paper and board
Corrugating media
Construction board

Some of the world's largest paper mills, each producing about 1,000,000 tonnes of packaging material, use no filler whatsoever.

Paper Industry–Structure, Size and Location

The accompanying map and tables (Figure 28) show the density and distribution of paper mills in the study area. Canadian statistics differ from those of the United States in that paper products are not separated by mill and mill location in Canada. Therefore, the Canadian facilities shown include non-filler plants such as pulp mills and construction board producers. However, detail is provided on a provincial basis by product type. As previously noted value of shipments, or total value of plant output, is used as the measure of industrial activity. In 1977 Canada had 68 paper mills and 89 pulp mills; the United States 728 paper mills and 334 pulp mills; and in comparison the United Kingdom had 147 paper mills and 7 pulp mills (Carnell 1977).

Of total paper and paperboard in Canada, 26 percent of production capacity (as measured by value of shipment) is located in Ontario, and 45 percent in Quebec. Beyond the study area, British Columbia has 15 percent and all other provinces combined 14 percent. Due to the volume of newsprint production in Canada (more than 60 percent of total paper production in terms of value) and the limited or non-existent filler potential in newsprint, Table 53 distinguishes newsprint from other paper products in Ontario and Quebec.

The study area includes 41 percent of the total United States paper and paperboard industry and 71 percent of the total Canadian paper and paperboard industry (Table 54). However, when industry segments are analyzed, the value of Canadian paper and paperboard not including newsprint is 81 percent within the study area, while 57.7 percent of the value of clay coated printing and converting paper produced in the United States is from the study area (Table 55).

Concentration ratios in manufacturing published by the United States government show that the 20 largest United States paper companies with multiple mill locations produce two-thirds of the total United States production, based on value of shipment.

Filler Consumption in Paper

The basic objective of both filling and coating is to provide a smooth, bright, receptive surface for printing. On uncoated and filled printing papers a technique called calendering is used, which consists of pressing the paper through polished rolls to smooth the surface. The mineral filler imparts opacity to the paper to inhibit "show through" (the ghosting through of printing when viewed from the reverse side of the sheet), and "strike through" (the wicking of ink from one side of the paper to the other).

On coated paper, application of the coating pigment plus binding adhesive (binder) is analogous to a paint being applied at high solids and high speeds to a paper substrate. The coated paper must be receptive enough to the printing ink to avoid "set off" (the transfer of ink from one sheet to the next), but also have enough holdout to provide gloss and ink colour fidelity.

Kaolin is the most abundantly used filler in the paper industry. The large universal use of various types of kaolin for both filling and coating recognizes the suitability of kaolin in the acidic paper making process, as well as the natural fineness of the colloidal kaolin particle and the superior viscosity characteristics that allow operations at high solids and high shear rates.

Talc is primarily used as a process aid in the production of paper, acting as a pitch control agent keeping pitch (organic contaminant in the fiber) dispersed in the system and preventing pitch agglomeration which can cause spots or holes in the paper.

Ground calcium carbonate can act as a filler in alkaline paper systems and as a coating pigment. Precipitated calcium carbonate, the synthetic material, is used in the paper industry at about twice the tonnage level of ground calcium carbonate.

Based on the distribution of the paper industry in Canada and the United States, it is apparent that kaolin use in the study area exceeds 60 percent of total Canadian and United States consumption. Consumers are particularly concentrated in Wisconsin, Maine, Pennsylvania, Ohio, New York, Michigan, Ontario and Quebec.

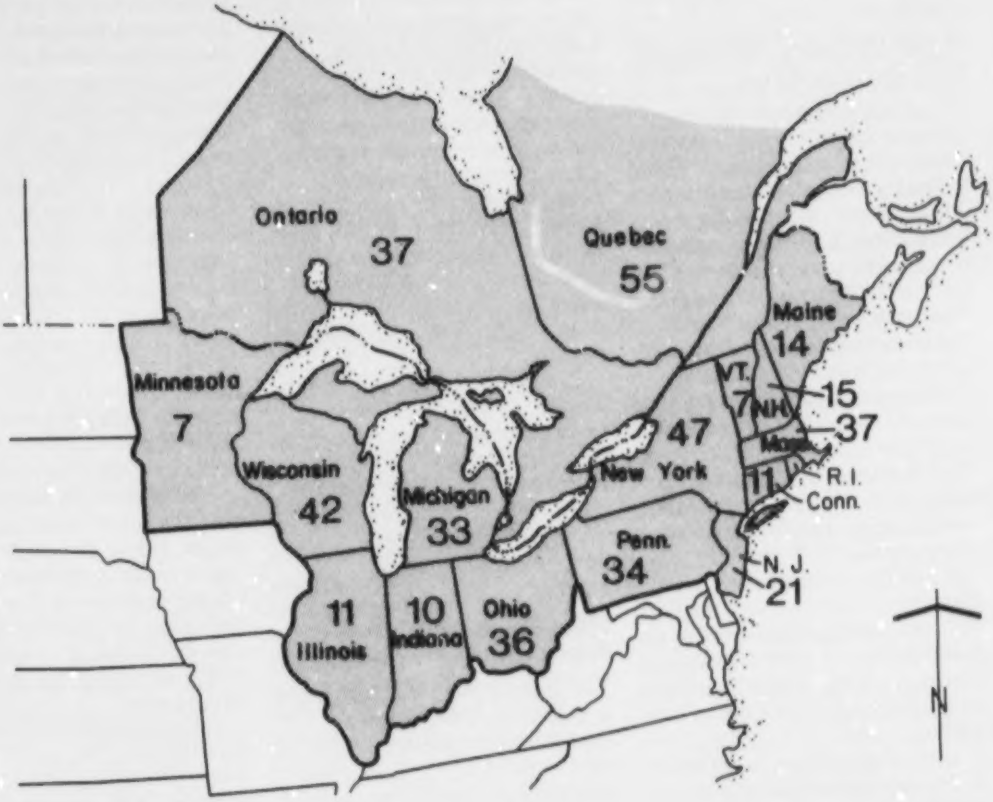
The major mineral fillers used

Table 53 Value of Paper Mill Shipments, 1978

Province	Total Paper & Paperboard	Newsprint	Total Less Newsprint
		Thousands of Canadian Dollars	
Ontario	1,246,399 (26%)	555,435 (19%)	690,964 (40%)
Quebec	2,117,714 (45%)	1,416,093 (47%)	701,701 (41%)
Other Provinces	1,365,445 (29%)	1,032,359 (34%)	333,086 (19%)
Canada Total	4,729,638	3,003,887	1,725,751

Figure 28

DISTRIBUTION OF PULP AND PAPER MILLS



1) CANADA	**Pulp & Paper Mills 1978**
Ontario	37
Quebec	55
Other Provinces	52
Total Canada	144

2) UNITED STATES	**Paper & Paperboard Mills 1977** 20 or more employees
Study Area (15 states)	325
Total U.S.A.	519

Sources: 1) Statistics Canada ; Pulp and Paper Mills, 1978, Catalogue 36 - 204

2) U.S. Department of Commerce; 1977 Census of Manufacturers; Pulp, Paper and Board Mills (SIC 2611, 7621, 2631, 2661), Industry Series Mc 77 - I - 26A

Table 54 Value of Paper and Paper Shipments

	Canada 1978 Millions of Can. Dollars	Percent of Total		United States 1977 Millions of U.S. Dollars	Percent of Total
Ontario	1,246.4	26	Study area (15 states)	8,034.8	41
Quebec	2,117.8	45	Other states	11,702.8	59
Other provinces	1,365.4	29	Total U.S.A.	19,737.6	100
Total Canada	4,729.6	100			

Table 55 State Ranking for Paper Within the Study Area

Value of Shipments

	Paper and Paperboard		Clay Coated Printing and Converting Paper	
	Millions of U.S. Dollars	% of Total	Millions of U.S. Dollars	% of Total
Wisconsin	1,825.5	9.3	439.5	19.4
Maine	1,222.6	6.2	429.6	19.0
Pennsylvania	940.5	4.8	57.2	2.5
Ohio	847.4	4.3	N/A	N/A
New York	805.8	4.1	167.3	7.4
Michigan	748.4	3.8	210.4	9.3
Massachusetts	446.1	< 3.0	N/A	—
Minnesota	395.7	< 3.0	N/A	—
New Jersey	308.7	< 3.0	N/A	—
New Hampshire	231.8	< 3.0	N/A	—
Illinois	153.2	< 3.0	N/A	—
Indiana	109.1	< 3.0	N/A	—
Connecticut	N/A	N/A	N/A	—
Vermont	N/A	N/A	N/A	—
Rhode Island	N/A	N/A	N/A	—
	8,034.8	40.7	1,304.0	57.7
Total U.S.A.	19,737.6	100.0	2,260.9	100.0

Sources: 1) Statistics Canada; Pulp and Paper Mills, 1978, Catalogue 36-204.

2) U.S. Dept. of Commerce; 1977 Census of Manufacturers; Pulp, Paper and Board Mills (SIC 2611, 7621, 2631, 2661), Industry series Mc 77-1-26A.

in the paper industry are kaolin, talc, and calcium carbonate. The features and benefits in paper applications for these three minerals are outlined in Table 56.

An estimate of filler consumption by the paper industry in Canada and the United States is given in Table 57. Of the 3.4 million tonnes of kaolin used in paper, about 2.2 million are consumed in the study area, but only about 180,000 tonnes of which are used in Ontario and Quebec.

Trends

The paper industry today is in a state of change both in regard to the paper products produced and the mineral fillers consumed. According to Busch (1980), Carnell (1977) and Hutchinson (1981) large increases in the production of coated paper are expected, and this is the largest filler consuming segment of the paper industry. In the early 1980's nearly 1,300,000 tonnes of new coated paper capacity were on stream or projected, more than 70 percent located in the study area.

A continuing interest in change from the acidic paper process favoring kaolin to the alkaline paper process favoring calcium carbonate is receiving widespread industry comment (McComb and Williams 1981; Paiste 1981).

In addition to its use for pitch control, research into the possible use of talc as a paper coating

Table 56 Features and Benefits of the Major Paper Fillers

Filler Type	Features	Benefits
Kaolin		
Air floated	Inexpensive; fine particle size.	Coating and filling use where high brightness is not required.
Water washed coating	White; good viscosity at high solids; fine particle size.	Allows high speed application and reduced drying costs.
Water washed filling	White; good retention; coarser particle size.	Universal filler in acid systems.
Water washed delaminated	White; high aspect ratios.	Gives light weight coating.
Water washed calcined	White; fine particle size.	Increased opacity.
Talc		
Micronized plates	Soft; white organophilic.	Pitch control; dispersion of organic contaminants to avoid spots or holes in paper.
Calcium Carbonate		
Ultra fine ground	White; bright; fine particle size.	Brightens paper; good ink receptivity.
Fine ground	White; bright.	Brightens paper, universal filler in alkaline systems.

Table 57 Estimated Annual Filler Consumption for Paper, 1980-1985

	CANADA AND UNITED STATES	STUDY AREA
	tonnes	
Kaolin	3,400,000	2,200,000
Talc	75,000	55,000
Ground Calcium Carbonate	125,000	80,000
	3,600,000	2,335,000

pigment (Eklund and Teirfolk 1981) is continuing.

These changes in consumption patterns will significantly affect the future markets for kaolin, calcium carbonate and talc. In addition, other trends such as the change from printed media to television advertising, the replacement of paper and paperboard products for packaging by plastic packaging materials, and the possibility of a "paperless" electronic communication system may have significant impact on the paper industry and its use of fillers.

Nevertheless, the United States and Canada are the leading world producers of paper, an industry almost unique in the manufacturing sector in that it is based on a renewable resource. It appears likely that the paper industry will continue to grow in the foreseeable future, particularly in Canada and the United States. Less certain are aspects such as a major replacement of kaolin by calcium carbonate through a change from acidic to alkaline paper processing, the continuing ability of kaolin producers to upgrade their products for better paper processing and improved paper performance, and the potential for talc in filling and coating applications.

Paint

Introduction

The paint industry, or more properly, the surface coatings industry, can be broken down into four main product groupings:

1. **Architectural Coatings**
   Coatings used in residential and commercial construction and maintenance; sold retail through company owned or independent outlets, or sold wholesale to contractors.
2. **Product Finishes**
   Coatings used in the manufacture of products such as automobiles and furniture; sold directly to the manufacturer and applied by the manufacturer.
3. **Special Purpose Coatings**
   Coatings for general maintenance purposes such as automobile refinish or repair, industrial maintenance coatings, traffic line marking paints and the general line of shelf goods (other than house paints) sold to the retail or industrial consumer through retail or wholesale outlets.

4. **Allied Products**
   Due to production capabilities and the availability of compatible sales outlets, paint manufacturers also can produce a suite of allied products such as putties, caulks, sealants, adhesives, inks, and spackling pastes. Most of these products use fillers.

Table 58 Composition of a Typical Interior Wall Paint

Item	**Kilograms**	**Litres**
Water	207.8	208.4
Additives	31.6	29.5
Prime Pigment	68.0	16.6
Vehicle (binder)	74.7	69.4
Extender Pigments		
Silica	7.7	2.9
Calcium Carbonate	56.6	21.0
Calcined Kaolin	22.7	8.8
Hydrous Kaolin	56.6	22.0
Total	525.7	378.6

Generally, the functions of a paint or coating are to protect, decorate and mask the surface being painted. Examples of these functions are:

Protection–The use of a paint to cover and preserve the metal parts on automobiles and to prevent rusting.

Decoration–The use of a colour top coating on an automobile or a piece of furniture for aesthetic purposes.

Masking–The use of a coating on rough wallboard, particle board or gypsum board to mask or hide the surface and its imperfections.

In many cases, a coating provides a single function such as the use of a primer to prepare a metal or wood surface for application of a decorative top coat. In other cases, all three functions are provided by a single coating, such as a house paint which fills imperfections in the house siding and at the same time gives a uniform colour, appearance and protection to the surface.

The following are a few of the variables in the formulation of paint, all of which may affect the selection and use of fillers, if any, in the paint formula:

Appearance (gloss, semi-gloss, flat)
Exposure (exterior, interior)
Quality, cost (low, medium, high)
Type (water based, solvent based)
Surface coated (Brick, stucco, cement, wood, metal, plastic)
Surface preparation (primed, unprimed)
Method of application (Brush, roller, spray)

A high quality gloss interior wood lacquer probably contains no filler. A flat interior, medium quality, water based wall paint probably contains a high level of filler. Filler functions in coatings encompass three areas: processing, application and finished coating performance. In processing, the filler can reduce costs, aid in coating stability and increase production speed. In application, the filler can aid in flow, film thickness and drying characteristics which affect the speed and ease of application. In finished coating performance the filler can impart improved characteristics to the coating, including durability, appearance continuity and uniformity on recoating or touch up.

Composition of a typical low cost interior wall paint is given in Table 58. Water comprises more than 60 percent of the total volume of the paint, both as a primary ingredient and as a part of the binder (which is 55 percent polymer emulsified in water).

Additives consist of nine separate chemical compounds used to modify viscosity, protect the vehicle emulsion, provide freeze/thaw stability, disperse the pigments, protect the paint from bacterial attack and prevent corrosion of the container.

The prime pigment is usually titanium dioxide which provides a paint film of high whiteness, brightness and opacity.

The functions of the various extender pigments are:

Silica: To flatten the gloss of the paint.
Calcium Carbonate: To build solids in the paint.
Calcined Kaolin: To space the titanium dioxide and achieve optimum opacity as well as providing opacity and whitness itself.
Hydrous Kaolin: To increase solids in the paint and aid in dispersion stability of the solids content.

Extender pigments, not including the prime pigment, comprise more than 27 percent weight of the paint and more than 14 percent of its volume. If the manufacturer's average cost for the four fillers is 22 cents per kg ($220 per tonne) the total filler cost is 8.3 cents per litre for a paint that may retail for $2.00 per litre. Raw material costs relate to the different specific gravities of the ingredients; raw materials are purchased by weight, but the paint is sold by volume. Anything a paint manufacturer can do to increase his yield in terms of volume, and reduce his weight per volume cost, generates profit. A one cent per litre saving on raw materials for a two million litre per year paint plant translates into a saving of $20,000.

The Paint Industry–Structure, Size and Location

The accompanying map and tables (Figure 29) show the density and distribution of paint plants in the study area. United States statistics differ from Canadian in that the United States differentiates between facilities with 20 employees or more, and facilities with less than 20 employees. Only the larger plants are noted on Figure 29. Four states, Maine, New Hampshire, Vermont and Rhode Island are not reported because they do not meet minimum reporting standards or were excused from reporting due to their small size. As is noted, 455 facilities with less than 20 employees are not allocated by state on the map. However, value of shipments for these facilities are included for eleven of the fifteen study area states reported.

Distribution of the Canadian paint industry is shown in Table 59.

Table 59 The Canadian Paint Industry, 1978

	Facilities	Value of Shipments Millions of Dollars
Newfoundland	1	n/a
Prince Edward Island	1	n/a
Nova Scotia	1	n/a
New Brunswick	1	n/a
Quebec	38	$139,277
Ontario	78	$341,801
Manitoba	5	$ 19,786
Saskatchewan	1	n/a
Alberta	5	$ 3,693
British Columbia	19	$ 63,826
Yukon and Northwest Territories	0	—
	150	$582,224

n/a = Data not available

The categories of products detailed in statistics for the United States are those previously described:

Architectural
Product Finishes
Specialty Coatings
Allied Products
Miscellaneous

Allied Products include wood and textile preservatives, wood fillers and sealers, putty and glazing compounds, paint and varnish removers, brush cleaners and other items not specified. Miscellaneous products include a variety of paint raw materials produced and sold as surplus to needs or purchased from others.

Extreme concentration is noted for the Canadian and United States paint industry: More than 80 percent of the Canadian industry is concentrated in Ontario and Quebec, and 50 percent of the United States industry is concentrated in six states (Illinois, Ohio, New Jersey, Michigan, Pennsylvania and New York). The three leading states (Illinois, Ohio and New Jersey, which are in the study area) individually exceed the entire paint industry of Canada as measured by value of shipments. Concentration in this study area of the three major paint categories ranges from 42 percent for architectural coatings to 60 percent for product finishes.

The twenty largest paint companies account for 51 percent of the total paint produced in the United States.

Filler Consumption in Paint

The primary function of paint is to protect, decorate and mask the surface. The surface can vary from a porous cement to an impervious metal. Thus, the formulations for paint, and therefore the filler requirements, if any, will also vary within wide limits. Table 60 outlines the most significant features and benefits of the major fillers used in the paint industry.

Barite's high specific gravity causes bulking value to be relatively low compared to other fillers. Therefore, the yield of volume to weight is low. While paint raw materials are purchased by weight, paint is sold by volume, and the paint manufacturer has an interest in gaining as much volume yield as possible. Nevertheless, barite's low oil absorption, easy wettability and good sanding qualities have resulted in its use as a major ingredient in automotive primers where colour is not critical.

Calcium carbonate can be exceptionally white and it has relatively low oil absorption. Low oil absorption allows higher levels of loading while retaining desirable viscosity and flow characteristics; hence lowering the cost of the paint. Calcium carbonate is the most abundantly used filler in paints.

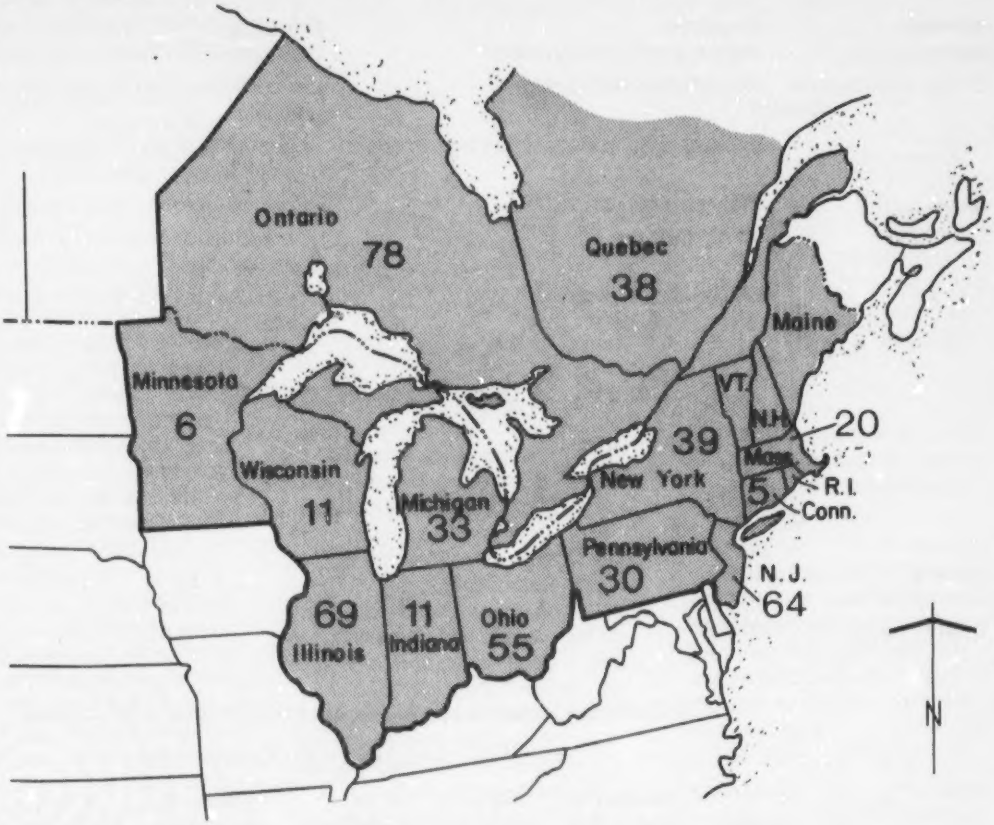
Kaolin has exceptionally good viscosity (flow) characteristics, especially water washed kaolin in water based paints. This contributes to good processing and application properties. Paint is second only to paper as a market for water washed kaolin.

Mica's platy particle shape gives a tough resistant characteristic to the paint film, aiding in stain removal and durability. Mica's lower brightness, compared to kaolin, talc and calcium carbonate, is the main drawback to its increased use in paints.

Silica's main characteristic of being hard and abrasive compared to other fillers is a drawback in many applications due to wear of process and application equipment. However, these properties become assets in applications such as traffic line marking where silica imparts abrasion resistance to the paint film. Synthetic silica is also universally used in small quantities to reduce gloss in paint films.

Figure 29

DISTRIBUTION OF PAINT MANUFACTURERS



1) CANADA	Paint Plants 1978
Ontario	78
Quebec	38
Other Provinces	34
Total Canada	150

2) UNITED STATES	Paint Plants 1977	
	20 or more employees	Total All Plants
Study Area (15 states)	343	798
Total U.S.A.	653	1579

Sources: 1) Statistics Canada, Paint and Varnish Manufacturers, 1978, Catalogue 46-210

2) U.S. Dept. of Commerce, Industry series Mc 77-1-28 E, 1977 Census of Manufacturers

Table 60 Features and Benefits of the Major Paint Fillers

Mineral	Features	Benefits
Barite	High specific gravity; inert.	Dense, resistant primer coating.
Calcium carbonate	White; low oil absorption.	Low oil absorption makes high loadings possible.
Kaolin	Fineness; good viscosity at high solids.	Suspension of paint ingredients; aid to opacity; ease of application.
Mica	Platy particle shape.	Aids in stain removal; durability.
Silica	Hard; inert.	Good abrasion resistance; flat paint appearance.
Talc	White; organophilic.	Good dispersion in solvent and water paints.

Table 61 Value of Paint Shipments

Canada 1978

	Millions of Can. Dollars	Percent of Total
Ontario	341.8	58.7
Quebec	139.3	23.9
Other provinces	101.1	17.4
Total Canada	582.2	100.0

United States 1977

	Millions of U.S. Dollars	Percent of Total
Study area (15 states)	3,682.0	55.5
Other states	2,947.7	44.5
Total U.S.A.	6,629.7	100.0

Six Leading States in the Study Area (Millions of U.S. Dollars)

			VALUE OF SHIPMENTS BY PAINT TYPE				
	Value	Percent of Total U.S.A.	Architectural	Product Finishes	Specialty Coatings	Allied Products	Miscellaneous
Illinois	865.7	13	351.4	243.5	72.8	14.6	67.7
Ohio	669.6	10	160.7	296.4	73.9	14.8	72.7
New Jersey	602.4	9	199.1	119.6	96.0	—	52.1
Michigan	509.7	8	35.9	340.2	42.5	2.7	41.6
Pennsylvania	342.6	5	113.2	118.6	29.2	6.8	7.3
New York	304.4	5	83.5	62.3	32.7		
	3,294.4	50	943.8	1,180.6	347.1	52.4	362.9
Other states in study area	387.6	5					
TOTAL U.S.A.			2,234.0	1,957.2	727.8	140.4	532.5
6 STATES % OF TOTAL U.S.A.			42	60	48	37	68

Sources: 1) Statistics Canada; Paint and Varnish Manufacturers, 1978, Catalogue 46-210.
2) U.S. Dept. of Commerce; 1977 Census of Manufacturers, Paints and Allied Products (SIC 2851) Industry Series MC77-1-28E

Paint is the largest consumer of ground silica fillers.

Talc can be readily wetted and dispersed in both organic solvent and water based paints, whereas most fillers are readily dispersed only in aqueous systems. Hence paint is a major market for talc, especially in all types of primers and flat coatings where its high oil absorption and surface roughness are advantageous. It is a useful filler for final adjustments in gloss, body, viscosity and solids content.

Based on the distribution of the paint industry, it is apparent that the study area represents more than 40 percent of total manufacturing capacity and 60 percent for product finishes.

These facilities are particulary concentrated in Illinois, Ohio, New Jersey, Michigan, Pennsylvania, New York and Ontario (Table 61).

Filler consumption in the Canadian and United States paint industry is estimated in Table 62.

Table 62 Estimated Annual Filler Consumption for Paint, 1980-1985

	U.S. & CANADA	**STUDY AREA**
	tonnes	
Barite	42,000	30,000
Calcium Carbonate	250,000	110,000
Kaolin	150,000	90,000
Mica	17,000	7,000
Silica	55,000	35,000
Talc	130,000	90,000
	644,000	362,000

Trends

There are continuing changes in the paint industry regarding formulating, processing, application and use. Also, the industry itself is undergoing consolidation through mergers and acquisitions. Large regional paint producers are acquiring local producers, a trend which may favour those filler producers with extensive distribution and multi-mineral capabilities.

Competition in the industry has stimulated a closer look at costs for transportation, purchasing, and inventory. Barite, mica and silica, relatively minor fillers used in the paint industry, may in some cases be replaced with calcium carbonate, kaolin and talc to simplify paint formulations and reduce inventory costs.

Slurry shipments of kaolin and calcium carbonate, or bulk truck deliveries of fillers unable to be shipped in slurry form, favour the large producer who can purchase or lease suitable transportation equipment and the large consumer who can receive such shipments.

Plastics and Rubber

Introduction

Historically, plastics and rubber were considered two separate industries; but this distinction is no longer clear. Not only is there an overlap in technology and application, but many plastic products have been substituted for traditional rubber products. Hence it is sometimes difficult for a non-technical person to determine if foam rubber is a rubber or a polymer based product. The same is true for such products as carpet backing and weather stripping.

Common understanding is that rubber is a natural product produced from latex harvested from the rubber tree; but this is no longer the only source. Many rubber products today are produced from synthetic compounds by technology similar to that used in polymer production. As a result the term "rubber" is often not technically correct and should be replaced by the term "elastomer".

Elastomers are plastics (i.e. polymers) that exhibit rubber-like characteristics such as elasticity, flexibility, softness and the capacity to rebound to their original shape after bending, twisting or compression. Polyurethane, while a plastic, exhibits these properties.

Plastics are produced from petroleum feed stocks where a monomer such as ethylene is converted into a polymer such as polyethylene.

Plastics can be divided into two sub groups:

1) Thermosets are complex organic chemical compounds that are irreversibly cured into finished products by use of catalysts, heat and pressure.

2) Thermoplastics are complex organic chemical compounds that can be reversibly melted, formed and remelted.

Plastic products are formed or produced by a variety of manufacturing processes such as:

Extrusion

Forcing the polymer through dies or rolls under the application of heat and pressure to form shapes or films.

Molding

Compression molding by forcing the polymer into a die using a combination of heat and pressure. Injection molding uses liquid polymer forced into a closed die under pressure and heat.

Vacuum Thermoforming

Softening or melting the polymer in a mold and forming its shape by the application of vacuum.

Liquid Systems

Liquid systems are two component systems consisting of a polymer and a catalyst that are mixed prior to use. These systems can be sprayed or built up by hand, such as in the building of fiberglass reinforced polyester boats. Alternatively, these systems can be cast, as in the case of synthetic marble top tables. Adhesives and automotive body repair compounds are other examples of two component liquid systems.

For purposes of this study, the various applications for elastomers and plastics are separated into major groups. These are plastics, elastomers, carpet backing and vinyl tile. The latter two are considered part of the "floor covering group", a significant consumer of mineral fillers that deserves separate distinction from elastomers and plastics. Caulks and sealants, while related to elastomers, will also be covered as a separate industry group.

Plastics are ubiquitous. One common plastic, polyvinyl chloride (PVC), finds use in clear plastic food wrap, rigid pipe for water or sewage, automobile and furniture upholstery, wall covering, floor tile and many other uses (Table 63). Plastics can also be combined into copolymers such as vinyl-acrylic systems which are used as emulsions to carry the pigment in paints.

All of these markets are served by thousands of chemical compounds (or combination of compounds), some of which use fillers and all have specific use and performance characteristics. The durability and flexibility of tires, the cyclical stress on a power transmission belt and the flexibility of hoses through extreme ranges of heat and cold are examples of desired elastomer characteristics (Table 64). Plastic and elastomer industries cover a spectrum that includes production of the base polymer, compounding, formulating and finally fabricating into a finished product. Specialty compounders may purchase the basic polymer, compound it and sell it to fabricators; they also do custom compounding. It is often the compounder who purchases mineral fillers for his pre-compounded products.

Competition exists between plastics and other fabricating materials such as metals, wood and other plastics.

Filler Use

The selection of a filler is based on the required product performance characteristics. In some instances, cost reduction will be the governing feature, while in others improved physical properties of the product are most important. More than one filler may be used to achieve either a syn-

Table 63 Major Markets for Plastics

Appliances	Refrigerator door liners; decorative and functional moldings on toasters and coffee makers.
Building	Pipe, weather stripping extrusion, siding, eavestroughing, foam insulation board, floor tile.
Electrical	Insulated electrical wire, cable coatings, printed circuit boards, transformer housings and office equipment.
Furniture	Wood grain or color decorative laminates; upholstery fabric.
Housewares	Dishes, utensils, no-stick coatings on cooking equipment, disposable cups, cutlery, stirring sticks, trays, etc.
Packaging	Bottles, cans, clear food wrap, trays, cartons, garbage bags, plastic cups.
Automotive	Fan shrouds, water reservoirs, fender liners, body panels, bumpers, dashboards, headliners, knobs, vinyl seat covers, padding, electrical wiring, floor covering, external decoration.
Toys	Dolls, models, kites.
Recreational	Fiberglass reinforced power and sail boats, surfing boards, skis, swimming pool liners.
Industrial	Plastic tubing, wear parts, pump liners, pipe and pipe linings.

Table 64 Major Markets for Elastomers

Tires	For strength and durability of the tread, and flexibility of the sidewall.
Belting	Power transmission, "V" belts, conveyor belting.
Hose	Power transmission fluids that are hot or corrosive.
Household Goods	Rubber mats.
Industrial Goods	Rubber floor mats, liners for corrosion protection, rubber coated equipment parts, pump liners, pipe lining, gasket materials, vibration damping mounts, etc.
Wire and Cable	High voltage power transmission cable.
Urethane	Elastomers that may be foamed (cushions), molded (automobile bumpers), cast or used in protective coatings.
Seals	Water proofing and weather proofing joints.
Footwear	Athletic shoes, heels, soles.
Latex Dipped Goods	Surgeons gloves and baby bottle nipples.
Silicone	An elastomer that can be used for sealant and adhesive applications.

ergistic effect or to gain improvements in several physical properties. One mineral filler may have significant benefit in one polymer system, but not materially enhance another.

Fillers can be separated into two distinct groups: functional fillers and reinforcing fillers.

The reinforcing properties of a filler may also be modified by the particle size distribution; finer fillers may show increased reinforcing properties. Surface treatment with coatings may assist the processability of the filler by improving dispersion in the polymer or elastomer. Coupling agents are designed to improve physical bonding between polymer and mineral particles.

Fillers in plastics and elastomers include glass fiber or flake, kaolin, talc, mica, silica and other non-metallic minerals. Producers are continually promoting and improving the reinforcing properties of their mineral fillers. Calcium carbonate is used extensively in plastics applications.

Fillers will continue to play a major role in the production of plastics and elastomers. Improvements in the processing technology of filler materials such as finer grinding, and treatments such as coatings and coupling agents, will continue to advance the utilization of mineral products as functional or reinforcing fillers.

The Industry

Canada

More than 85 percent of all plastics and rubber fabricating is centered in Ontario and Quebec (Figure 30). Statistics for Canada in the three listed industry groupings for 1978 are given in Table 65.

United States

Concentration of plastics and rubber production in the study area varies by category, ranging from 3.7 percent for tufted carpets, an industry concentrated mainly in Georgia and South Carolina, to 84.3 percent for automotive trim concentrated mainly in Michigan. Production details by specific category are given in Table 65.

The impact of large companies on total United States production of various plastic and rubber products is shown in Table 66. The data reveals hard surface floor covering to be a highly concentrated industry, while miscel-

Table 65 Value of Shipments for Plastics, Rubber, Wire and Cable Products

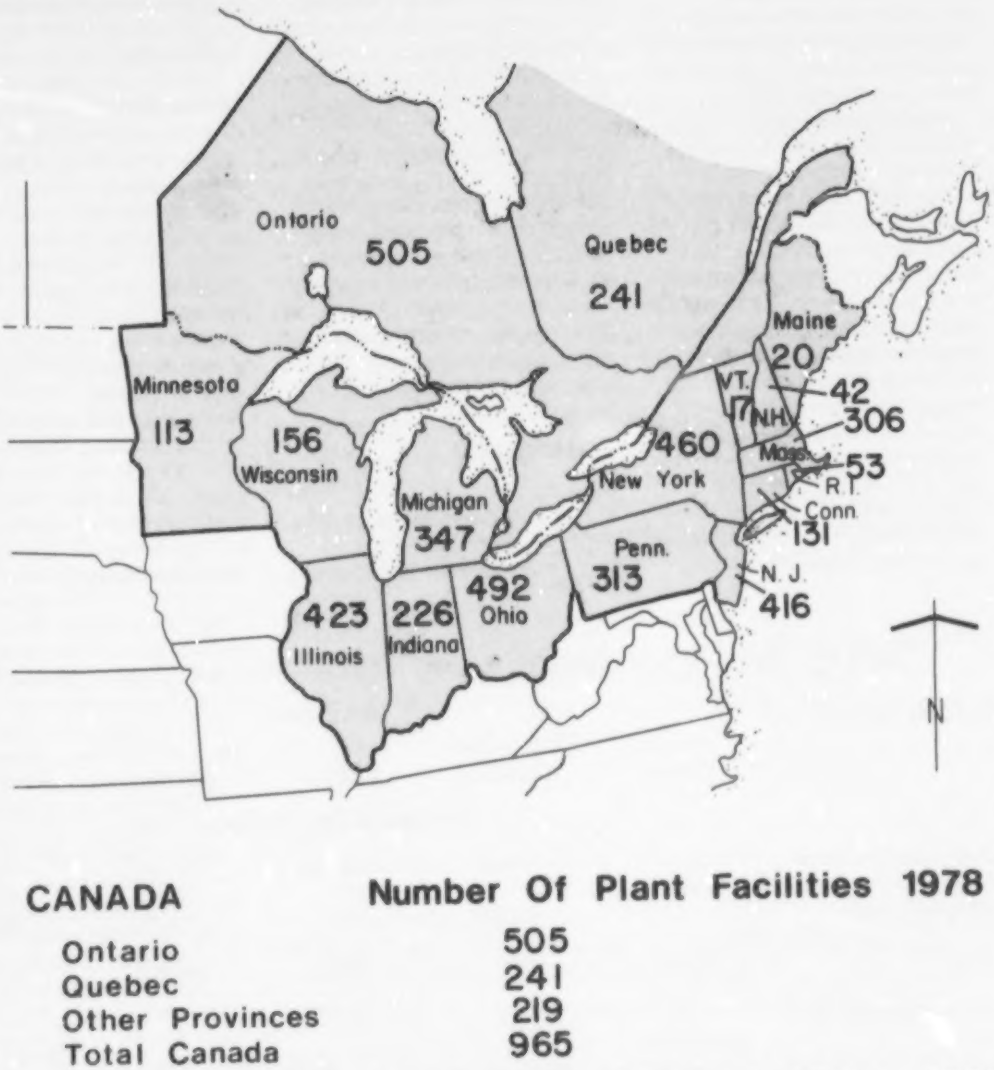
Canada 1978	**No. of Plants**	**Ont. & Que. Ontario**	**Quebec**	**Canada**	**% of total**
		Millions of Can. Dollars			
Fabricated plastics	814	985.2	394.9	1554.0	88.8
Fabricated rubber	109	862.6	260.1	1306.4	85.9
Wire and cable	42	414.7	290.2	792.6	88.9
Total	965	2262.5	945.2	3653.0	87.8

United States 1977	**Total U.S. Plants**	**Study Area**	**United States**	**Study Area % of total**
		Millions of U.S. Dollars		
Tires and tubes	200	2462.0	8971.0	27.5
Footwear	84	86.2	517.0	16.7
Hose and belting	146	243.0	1765.7	13.8
Other rubber products	1280	2692.7	4565.0	59.0
Misc. plastics	10212	7406.1	23688.4	31.3
Wire and cable	421	3979.9	6595.4	60.3
Tufted carpets	449	166.7	4520.7	3.7
Hardsurface flooring	21	439.4	607.2	72.4
Auto trimmings	714	1825.6	2165.7	84.3
Total	13527	19301.6	53396.1	36.1

Sources: Statistics Canada and U.S. Dept. of Commerce (as detailed in text).

Figure 30

PLASTICS, RUBBER, WIRE & CABLE PLANTS



1) CANADA	Number Of Plant Facilities 1978
Ontario	505
Quebec	241
Other Provinces	219
Total Canada	965

2) UNITED STATES	Number Of Plant Facilities 1977	
	20 or more employees	Total all plants
Study Area (15 states)	3,515	–
Total U.S.A.	6,057	13,527

Sources: Statistics Canada and U.S. Dept. of Commerce (as detailed in text) laneous plastics are produced by a much more fragmented industry.

Data sources for the accompanying tables and map were obtained from the following sources. These data are reviewed on an annual, bi-annual or five year frequency.

1. Plastics Fabricating Industries, 1978, Catalogue 47-208, Statistics Canada.

2. Rubber Products Industries, 1977, Catalogue 33-206, Statistics Canada.

3. Manufacturers of Electric Wire and Cable, Catalogue 43-209, Statistics Canada.

4. 1977 Census of Manufacturers, Bureau of Census, U.S. Department of Commerce:
   a. Rubber and Miscellaneous Plastic Products Industry, Series MC77-1-30A
      SIC 3011 Tires and Inner Tubes
      SIC 3021 Rubber and Plastic Footwear
      SIC 3041 Rubber and Plastic Hose and Belting
      SIC 3069 Fabricated Rubber Products N.E.C.
      SIC 3079 Miscellaneous Plastic Products
   b. Nonferrous Metal Mills and Miscellaneous Primary Metal Products, Industry Series MC77-33D
      SIC 3357 Nonferrous Wire Drawing and Insulating
   c. Floor Covering Mills Industry Series MC77-1-22D
      SIC 2272 Tufted Carpets and Rugs
   d. Miscellaneous Manufacturers Industry Series MC77-1-39D
      SIC 3996 Hard Surface Floor Coverings
   e. Miscellaneous Fabricated Textile Products Industry Series MC77-1-23E
      SIC 2396 Automotive and Apparel Trimming

Table 66 U.S. Manufacturing Plants
Plastic and Rubber Products

Industry Sector	**Classification**	**Percent of Total Production By 20 Largest Companies**
Hard surface floor coverings	(SIC* 3996)	100%
Automotive trimming	(SIC 2396)	80%
Insulated wire and cable	(SIC 3357)	80%
Miscellaneous plastics	(SIC 3079)	21%
Rubber and plastic footwear	(SIC 3021)	89%
Rubber and plastic hose & belting	(SIC 3041)	91%
Fabricated rubber products, NEC**	(SIC 3069)	40%
Tires and tubes	(SIC 3081)	96%

* Standard Industrial Classification
** Not elsewhere classified

Source: 1977 Census of Manufacturers, Bureau of Census, U.S. Dept. of Commerce.

Table 67 Filler Utilization in Plastics and Elastomers

	Plastics	**Elastomers**
	Percent of Total Consumption	
Calcium Carbonate	82	18
Kaolin*	14	86
Talc**	65	35
Silica***	73	27
Mica	70	30
Barite	73	27

*Most of the kaolin used in elastomers is low cost air floated kaolin.
**Most of the talc used in plastics is platy talc from western United States sources.
***Ground silica only.

Filler Consumption

The choice of fillers used in plastics or elastomers relates directly to the desired characteristics of the final product. Each mineral filler has its own performance characteristics when used in a polymer.

The properties the filler contributes to the finished product may be due to its particle shape, particle size, inertness, wetability, its resin or oil absorption, freedom of moisture, colour or refractive index. Treatment with coating or coupling agents may modify or enhance the properties the filler imparts to the finished product.

The most critical aspects of filler sales are adherence to specifications and reliability of supply and cost. In many instances one of several fillers could be used in a certain application, and the final selection will be based on cost effectiveness, taking account of product performance and overall production cost. The distribution of use between plastics and elastomers for the common filler minerals is estimated in Table 67. Estimated filler consumption is given in Table 68.

The features and benefits of the mineral fillers covered in this study can be summarized as follows:

Barite

Features	High specific gravity; inert; low oil absorption
Benefits	High loadings possible; good disperson in polymers; good weighting agent.
Comments	Used in products where increased weight is desired, such as in foamed elastomers. Filler grades are costly and availability is low to average because there are a limited number of producers.

Calcium Carbonate

Features	High brightness; soft; low abrasion; relatively low oil absorption. Good availability.
Benefits	Can be considered an all-purpose functional mineral filler; a relatively low cost resin extender.
Comments	Modification with organic coating enhances its usefullness in many plastics applications, allowing higher loadings, improved wetability in the polymer and better overall performance. Calcium carbonates are available in a multitude of grades, differentiated by particle size, colour and surface treatment.

Kaolin

Features	Wide range of products; air floated, hard and soft kaolin, water washed, delaminated and calcined grades.
Benefits	All purpose filler in elastomers; also useful in plastics. Contributes excellent electrical properties, important in cable and wire coatings. Provides good flow characteristics during molding or extrusion.
Comments	Of lower brightness generally than calcium carbonates; higher oil absorption. Good availability. Air floated grades of kaolin are relatively low cost products. Their primary use is in elastomers.

Mica

Features	Platy particle shape; high aspect ratios.
Benefits	Delaminated mica is an excellent reinforcing filler for plastics. Used in elastomer production as a mold release and as an anti-sticking agent.
Comments	Mica has excellent potential as reinforcing filler. The limited availability of delaminated, high aspect ratio mica is a constraint to its more extensive use. Muscovite and phlogopite mica are the most commonly used types of mica.

Silica	
Features	Hard, chemically inert, low oil absorption, abrasive.
Benefits	Used where abrasion resistance is required.
Comments	Used primarily in selective applications such as in two component polyester, epoxy resins and polyurethane foam. High abrasion limits its use in extrusion or molding systems. Good availability.
Talc	
Features	Soft. Platy or fibrous forms. Talc is organophyllic and inert.
Benefits	Provides some reinforcing, increased impact resistance and heat deflection temperatures. Easy to disperse in most polymers. Used in elastomers as a mold release agent.
Comments	Preferred filler in polypropylene for its good impact resistance. Used extensively in two-component automotive body repair compounds.
Dolomite	
Features	High brightness; relatively low oil absorption.
Benefits	Same as for calcium carbonate.
Comments	High quality, high brightness dolomite is not commonly used in North America. It is used extensively in continental Europe as a filler in plastics. Dolomite of good colour is used in carpet backing.

Table 68 Estimated Annual Filler Consumption in Plastics and Rubber, 1980-1985 (Excluding Carpet Backing)

	Total Canada and United States	Study Area
	Tonnes	
Barite	20,000	8,000
Calcium Carbonate	500,000	375,000
Kaolin	300,000	200,000
Mica	10,000	5,000
Silica (ground)	20,000	13,000
Talc	72,000	40,000
Total	922,000	641,000

Carpet Backing

Significant quantities of mineral fillers are used in the production of foamed carpet backing. Relatively low cost, coarse, off colour grades are adequate. Several filler minerals can be used, but calcium carbonate is by far the most common. Carpet backing is the largest volume industrial application for calcium carbonate. Dolomite can be used equally well if it is white and free of abrasive materials.

The carpet industry in the United States is concentrated mainly in the Southeast in close proximity to major filler producers in Georgia and Alabama. Within the study area there is only minor carpet production in the United States, but significant production in Ontario and Quebec.

Statistics for mineral filler consumption in carpet backing are given in Table 69. Of these minerals only calcium carbonate is used in significant volume, mostly for markets in Eastern Canada. Relatively coarse grades of calcium carbonate (70 to 90 percent passing 200 mesh) are used, valued at about U.S. $25 per tonne in bulk.

Most of the foamed carpet backing is produced directly by carpet manufacturers but some is made by individual compounders who sell their products to the carpet manufacturers.

High filler loadings are used in carpet backing, with levels as high as 400 parts of filler per 100 parts of polymer. Colour is often of minor concern, allowing regional producers of lower quality products to service this market. Alternatively it affords producers of high quality products a market for some of their lower grade by-products.

Because of the low inherent value of the fillers used in this application, a producer must have a relatively large volume market to achieve efficient low cost production.

Vinyl Tile

A significant amount of the calcium carbonate used by the plastics industry is consumed in the production of vinyl floor tile and other hard surface flooring products. Granular or coarse ground products of good white colour and controlled particle size are used in this application, and filler loadings may be as high as 50 percent.

Polyvinyl chloride (P.V.C.) is the leading polymer in which significant amounts of mineral filler are used, with vinyl tile the single largest consumer of calcium carbonate. It is estimated that of the total amount of calcium carbonate consumed by the plastics industry, vinyl tile accounts for about half. It is a high volume, low value application. As such it has a significant impact on the average price of calcium carbonate fillers, which is estimated at U.S. $132 per tonne.

Table 69 Estimated Annual Filler Consumption in Carpet Backing, 1980-1985

	Total Canada and United States	Study Area
	Tonnes	
Barite	2,000	200
Calcium Carbonate	500,000	50,000
Kaolin	11,000	1,000

Putty, Caulks and Sealants

Introduction

Putty, caulks and sealants are a large diversified group of products with wide ranging industrial applications such as in architecture construction, automotive, electrical, aircraft and other engineering applications. As an industrial group, putty, caulks and sealants consume more filler per pound of finished product than any other filler application.

Putty, caulks and sealants are used to seal joints, fill seams, nail holes, cracks, dents, etc. With the exception of drywall compounds, they are rubber-like substances which retain their flexibility and resilience after curing. Putty, caulks and sealants are used to form a seal between similar or different materials. They have the ability to adjust to different expansion rates of dissimilar materials during changes in temperature without cracking, and in general have excellent resistance to all weather conditions.

The use of caulks and sealants has expanded over the last decade, particularly in industrial and residential building construction as a means of reducing heat loss. They are also used extensively in many other industrial applications, and this is the area of greatest growth potential.

Putty is the traditional product used in glazing. The advent of prefabricated aluminum window units has reduced its use in new residential and industrial construction, but it still retains its position as the traditional method of installing and sealing glass in wooden frames. Putty is a minor portion of the putty, caulk and sealant industry, consuming approximately five percent of the total amount of filler used in this group.

Dry sealants are used in wall jointing compounds in industrial and residential construction. The dry powder is mixed with water to produce a paste that can be troweled over the tape joints in drywall construction. It is also used for filling nail or screw holes and dents. After drying, the sealant can be sanded to a smooth finish.

Premixed sealants are becoming readily available. These consist of a premixed paste ready for application, which cures by exposure to air.

Caulks and sealants are the growth members of this industrial group of products. Caulks in particular are becoming more exotic in composition, properties and applications. The estimated annual volume of putty, caulks and sealants produced in North America is approximately 225 million kilograms with a value of approximately Can. $800 million, excluding the drywall jointing compounds. Industrial and construction uses consume two thirds of total production. Consumer usage accounts for the remainder.

Production of putty, caulks and sealants, including the drywall jointing compounds is concentrated in the highly populated areas of the northeastern United States, the United States midwest and the United States west. In Canada production is concentrated in the major industrial areas of Ontario, Quebec and the West. About 60 percent of all putty, caulks and sealants produced in North America originates in the geographic area covered by this study.

Filler Use

Almost all putty, caulks and sealants contain one or more mineral fillers. The fillers are added to provide body, smooth flow, anti-sagging, anti-cracking and improved weathering. Some fillers contribute reinforcing properties as well. However, the main filler purpose is to reduce the volume of costly polymer.

The amount of filler used in any application depends on the polymer type and the intended application for the product. Each filler is added to enhance specific physical properties and to improve product performance. Loadings may range from as low as five to as high as eighty percent. Putty and drywall jointing compounds are the most heavily filled.

Calcium Carbonate

Ground calcium carbonate is the most widely used filler in putty, caulks and sealants. The estimated consumption in North America is in the order of 500,000 tonnes, with a value of approximately Can. $21 million. Most of the calcium carbonate is consumed in the production of drywall jointing compounds, which utilizes the coarser, lower value grades. Dolomite, of good colour, can be substituted for calcium carbonate in drywall jointing compounds. Liquid or paste type caulks and sealants use high grade, high brightness, fine or very fine calcium carbonates with a much higher product value. Putty is highly filled with calcium carbonate (up to 80 percent) which is practically the only filler used.

Calcium carbonate consumption in putty, caulks and sealants is estimated as follows:

	Tonnes	% of Total
Drywall Jointing Compounds	400,000	84
Caulks and Sealants	50,000	10
Putty	30,000	6
Total	480,000	100

Most, but not all, caulks and sealants utilize calcium carbonate as a filler. Calcium carbonate is used because of its natural low binder demand (allowing high filler loading), good white colour and flow properties. It is readily available and of relatively low cost. Calcium carbonate is used in caulks and sealants made from polybutane, butyl and acrylic based polymers.

Talc

Talc is the second most widely used filler in putty, caulks and sealants. Like calcium carbonate, talc is used extensively in drywall jointing compounds. It also finds application in many types of liquid caulks and sealants.

North American consumption of talc in putty, caulks and sealants is estimated at 61,000 tonnes with an approximate value of Can. $7.3 million. Lower priced, lower quality talc is used in drywall jointing compounds, while high quality Eastern or Western talcs are used in caulks and sealants.

Filler levels for talc in putty, caulks and sealants range from 5 to 15 percent.

Talc consumption in putty, caulks and sealants is estimated as follows:

	Tonnes	% of Total
Drywall Jointing Compound	35,000	57
Caulks and Sealants	25,000	41
Putty (Automotive)	1,000	2
Total	61,000	100

Talc is used in drywall compounds because it contributes reinforcement and good sanding properties. Western talcs impart good thixotropy and reinforcement to liquid caulks and sealants while Eastern talcs contribute to good flow properties. Talc is used in butyl based caulks and acrylic or polyurethane based sealants.

Mica

Mica is used in minor amounts in putty, caulks and sealants. Its application is almost exclusively in drywall jointing compounds.

Annual mica consumption in North America in drywall jointing compounds is estimated at 60,000 tonnes. Mica provides reinforcement, thixotropy and crack prevention in drywall jointing compounds. Only white or off-white grades of muscovite or phlogopite mica can be used. The minus 100 or 200 mesh dry ground grades are the most commonly used.

Colour is an important consideration in the use of mica; dark minerals cannot be tolerated. Mica sold in this application has a value of $160 to $220 per tonne. In the United States approximately one third of the mica consumed in the production of drywall jointing compounds is produced by U.S. Gypsum Company for its own use.

In comparison to other fillers used in drywall jointing compounds, mica is an expensive filler. Its addition rate is approximately 8 to 14 percent by weight.

Kaolin

Kaolin is a relatively minor filler in putty, caulks and sealants. Air floated kaolin is the most common grade used, but water washed and calcined grades are also used. Kaolin is used in liquid caulks, sealants and putty, but not in drywall jointing compounds.

Air floated kaolin is commonly used as a filler in butyl caulks and acrylic sealants, but is also used in small quantities in other polymer systems. Water washed kaolin is used in caulks and sealants requiring good colour and smooth flow properties.

Calcined kaolin is used in high quality bathroom caulks where high whiteness is required. Calcined kaolin acts as a titanium dioxide extender reducing the amount of this expensive pigment required in the caulk.

North American consumption of kaolin in putty, caulks and sealants is estimated at 11,000 tonnes, of which 80 percent is air-floated kaolin; the remainder split between calcined and water-washed kaolin. Kaolin use in the geographic area covered by this study is estimated at 6,000 tonnes. Putty, caulks and sealants are a minor market for kaolin products.

Silica

Ground silica finds only limited use in putty, caulks and sealants. Its primary application is in sealants used in electrical applications. Consumption of ground silica in putty, caulks and sealants is estimated at about 1000 tonnes for all of North America, of which 500 tonnes is in the study area.

Barite

Ground barite is used to a limited extent in sealants requiring high density or chemical intertness. Barite is also used to improve the sound deadening properties of vinyl plastics sealants used in the automotive industry.

The consumption of barite in putty, caulks and sealants in all of North America is estimated to be less than 500 tonnes per year, of which the study area may account for 300 tonnes.

Table 70 Annual Filler Consumption in Putty, Caulks and Sealants, 1980-1985

Estimated Market in Canada and United States

	Drywall Compounds	Caulks & Sealants	Putty
		Tonnes	
Calcium Carbonate	400,000	50,000	30,000
Talc	35,000	25,000	1,000
Mica	60,000	—	—
Kaolin	—	10,000	1,000
Silica (ground)	—	1,000	—
Barite	—	500	—
Total	495,000	86,500	32,000

Estimated Market in the Study Area

	Drywall Compounds	Caulks & Sealants	Putty	Average value per tonne Can. $
		Tonnes		
Calcium Carbonate	250,000	30,000	20,000	45
Talc	20,000	15,000	1,000	115
Mica	28,000	—	—	220
Kaolin	—	5,000	1,000	140
Silica (ground)	—	500	—	175
Barite	—	300	—	270
Total	298,000	50,800	22,000	

Filler Consumption

Estimated filler consumption in putty, caulks and sealants is shown in Table 70.

The value of fillers used in putty, caulks and sealants is generally lower than for such applications as paints, plastics, elastomers and paper. Putty, caulks and sealants can be grouped with carpet backing and vinyl floor tile as high volume, low value filler applications. The low value of calcium carbonate in these applications is influenced by the high volume of low cost grades used in drywall jointing compounds.

Generally, the high volume, low value filler grades are produced with simpler processing techniques and equipment. Nevertheless, it requires a very efficient operation to economically produce the volume and quality of filler needed. This is particularly true for calcium carbonate which enjoys large volume sales in the lower priced applications such as carpet backing, vinyl tiles and drywall jointing compounds. Efficient production techniques combined with high sales volumes are necessary for success.

High volume filler users with multiple plants are likely to purchase their requirements on a contract basis. Purchase decisions are initially made on product performance, but ultimately it is the cost of product plus transportation cost that will be the determining factor. Fillers consumed in lesser volumes may be purchased through agents or distributors, while larger volume purchases are usually direct from the producer. It is normal for companies to qualify products from more than one supplier, and split purchases as needed to assure continuity of supply should one supplier experience difficulties. Large filler users, such as for drywall jointing compounds, buy their major fillers in bulk, while smaller volume purchasers purchase their products in 22.7 kg multi wall paper bags.

Transportation is usually by truck or rail depending on the distance and the facilities available at the receiving plant. Transportation costs are a significant portion of the total material costs, and considerable efforts are made by filler producers to minimize them.

Adhesives

Introduction

Adhesives, such as glue, contact cement, and other bonding agents, are a diverse group of chemical products used in many industrial applications such as construction, furniture, footwear, The main deposit, and other similar occurrences nearby, are nearly vertical lenses of coarse grained phlogopite, which comprises 85 to 90 percent, with minor feldspar and pyroxene, and traces of apatite, calcite, chlorite and opaque minerals. Some 20 million tonnes have been proven in the main deposit, which is 330 m long by up to 60 m in surface width. The deposits occur in high grade metasedimentary terrains intruded by a variety of igneous rocks.

Statistically, adhesives and sealants are in a single industrial group (SIC Code 2891). Statistical sources (1977 census of manufacturers) indicates a total of 572 sealant and adhesive producers in the United States of which some 300 are located within the study area. Of the total, 515 companies reported a level of 75 percent specialization. The adhesives segment of the industry reported sales in excess of one billion dollars (U.S.) in 1977. Anticipated sales of adhesive products in 1982 are estimated at over two billion dollars (U.S.).

Vegetable or animal-based adhesives form the smallest segment of this industry and account for approximately 14 percent of sales. Rubber and synthetic resins account for the remaining sales.

The leading states within the study area are New York, Illinois, Ohio and New Jersey. Production in Canada is concentrated in southern Ontario and Quebec.

Filler Use

Barite and mica find very little application in adhesives. All the other minerals in this study are used in significant volumes.

Calcium Carbonate

Finely ground (15 micron or less) calcium carbonate is used as a filler in all types of adhesives. Its primary function is cost reduction. Addition of calcium carbonate to adhesives also reduces the penetration of the adhesive into porous substrates, such as wood.

Particle size in many instances is more critical than colour. However, a good white colour is preferred in most applications.

Addition rates may range from as low as a few percent to as high as 50 percent.

Air Floated Kaolin

Air floated kaolin is the most commonly used mineral filler in adhesives. It is used in such large volume adhesives as floor tile, panelling, construction and packaging–adhesives that are applied by trowelling. Kaolin improves the trowelling and flow properties and reduces the cost of the adhesive. Air floated kaolin is the lowest cost kaolin product.

Water Washed Kaolin

Water washed kaolin is used in all types of adhesives. Major application areas are in construction and packaging. Kaolin is used to control the viscosity of water based adhesives. It also improves stiffness, reduces penetration of the adhesive and imparts good flow properties. Its primary function is to reduce cost of the final product without adversely affecting physical properties.

Talc

Platy talc is used in synthetic rubber-based adhesives. Besides reducing cost, talc contributes to improved electrical properties and chemical resistance.

Silica

Synthetic and ground silicas are used in rubber and synthetic resin-based adhesives. However, the use of ground natural silica is minor compared with precipitated, pyrogenic silica or silica gel.

Filler Consumption

Total mineral filler consumption in 1977 was 106,000 tonnes with a value of U.S. $8.5 million. The adhesives industry produced 3.3 million tonnes of adhesives with a value of U.S. $1.4 billion in 1977 (Kline 1978).

Kaolin consumption (all types) was estimated at 87,000 tonnes of which 68,000 tonnes was air floated kaolin.

Ground calcium carbonate accounted for 13,500 tonnes, and talc for 2,700 tonnes. Ground silica was less than 400 tonnes (Kline 1978).

The use of calcium carbonate is expected to grow, while kaolin consumption is expected to decline. Filler consumption by the adhesives industry has been relatively stable during the period 1977-1982 despite the significant growth in adhesives.

It is expected that mineral filler consumption will not grow significantly during the next five years. There has been a shift towards hot-melt adhesives which use little or no mineral fillers. The future growth rate of filler consumption in adhesives will likely be less than the growth rate for adhesives.

11 Transportation

Introduction

The movement of filler products from the producer to the consumer, either directly or through a distributing warehouse, involves a variety of transportation modes and packaging techniques. In many instances, transportation costs exceed the base value of the filler at the mine or plant. It is obviously in the producer's best interest to constantly seek the lowest cost transportation to maintain his competitive position.

Terms of sale may or may not include transportation costs. Producer's prices are normally quoted without transportation costs (i.e. f.o.b. producer's plant or mine). The additional cost for haulage will vary with the level of consumption (unit load versus part load), form of the shipment (bagged, bulk, slurry), and type and complexity of the transportation mode (truck, rail, or both).

Unless his filler requirements are small, a consumer may divide his needs between two or more producers to ensure continuity of supply in the event of unforeseen interruptions due to strikes or other work stoppages.

Point-to-point freight rate comparisons in general only indicate relative distances from producers to consumers. Actual freight costs are determined by negotiation, and are almost constantly under review, having in mind the competitive threat of other minerals and sources, and other transportation modes. Indeed, each producer (point of origin), consumer (destination), mineral type and form of shipment is subject to specific detailed analysis in determining overall transportation cost.

Aspects of Transportation Related to Mineral Characteristics

The physical characteristics of the mineral largely determine the manner, method, mode and cost of transportation. The first factor in transportation is the bulk density (weight per unit volume) of the mineral; it determines bag size and cost, loading techniques and ultimate weight of bulk containers.

Bulk density is sometimes confused with bulking value (weight per unit volume in the dispersed state), which is a constant for any mineral type just as is specific gravity. Bulk density however, relates to the physical form of the mineral, and it can vary. For example, spray dried kaolin in the form of microspheres can have three times the bulk density of a pulverized conventionally dried kaolin. Pelletized or compacted talc, which has the entrained air removed from normal dry powdered talc, increases bulk density dramatically. The higher the bulk density, the lower the cost of bagging and the higher the weight that can be loaded and transported, whatever the manner and mode of transport.

The physical form of the mineral also affects its dry flow characteristics in gravity or pneumatic systems. Angle of repose is one measure of the flowability of a mineral. A high angle of repose indicates poor flowability.

The practice of shipping certain fillers in slurry form has increased markedly in recent years. It has advantages for both producer and consumer: The producer saves on drying and handling costs, and on bag costs and bag losses due to spillage and breakage; the consumer is assured of a more uniform product less likely to be contaminated and more ready for use.

The only fillers presently shipped routinely in slurry form are kaolin and calcium carbonate. The slurry normally consists of 70 percent filler and 30 percent water, but the consumer pays only for the weight of filler on a dry basis. Obviously, the only applications that can use this form of shipment advantageously are wet ones, such as in the making of water based paints and in filling and coating paper. High solids content of the slurry is required to avoid dilution problems in a system such as paint. Because the mineral is in the fully dispersed state when shipped in slurry form, bulking value is significant rather than bulk density when calculating weight per unit volume.

Mode of Transportation

Fillers may be shipped by road, rail or water, in bagged, bulk or slurry forms. Bagged and bulk shipments are more versatile in that they can be shipped by all three methods; slurry shipments are normally limited to tank truck or railway tank car.

Bagged shipments are less vulnerable to contamination, and most easily transferred from one haulage system to another. Bags are equally suited to truck, rail car, ship, barge, or container. Bags are also the most expensive form in which to ship.

Bulk shipments are normal where the consumer's needs are sufficiently large. Covered railway hopper cars or highway trucks with bottom dump or pneumatic unloading systems are preferred. Bulk shipments can also be transported by ship or barge. Sparger rail cars provide a means of dispersing the filler by introducing water or air at the destination and pumping it to the processing facility.

Intermodal shipments are possible, such as the piggyback movement of truck trailers or containers by rail. Multiple mode shipping is also possible, though expensive because of excessive handling; shipments may be railed to port, off loaded to ship or barge, and finally delivered by truck to consuming plants.

In some cases, unusual shipping problems may require special loading or hauling equipment which the producer may have to purchase or lease; or a producer may purchase or lease a fleet of trucks or rail cars to be assured of their availability and freedom from contamination.

Transportation Costs

Prior to the energy crisis, transportation cost comparisons could be reasonably defined by using point-to-point rail freight rates and published truck freight rates. Since 1973, the gross escalation of fuel costs and the increased costs of carrying inventories have drastically changed the mechanisms for transportation from mine to market. Some of these changes are:

1. Switching from rail to truck delivery speeds transit time and reduces the size of the load received, thus reducing the size of the inventory storage capacity required. Truck delivery also provides single carrier straight-through hauls that avoid multi-line rail hauls and marshalling yard congestion delays.
2. The use of contract trucks, trip leased trucks, back haulers (trucks carrying return loads to home base), and producer or consumer owned trucks allow negotiated rates for individual hauls or long term contracts at less than normal rates.
3. Economy may be achieved by the switch from bagged shipments to bulk and slurry shipments even though the producer may have to purchase or lease the transporta-

Table 71 Rail Freight Rate Comparison, 1981, and Highway Distance Chart (U.S. Dollars per short ton at indicated minimum loads)

Fillers at Various Points of Origin	**Chicago Illinois**	**Detroit Michigan**	**Cleveland Ohio**	**Toronto Ontario**	**New York New York**
Barite					
Cartersville, Ga.	42.00 (80M)*	42.40 (80M)	42.40 (80M)	58.61 (80M)	48.97 (80M)
	1086 km	1110 km	1068 km	1482 km	1398 km
Calcium Carbonate					
Cartersville, Ga.	38.60 (80M)	38.60 (80M)	38.60 (80M)	81.20 (80M)	46.00 (80M)
	1086 km	1110 km	1068 km	1482 km	1398 km
Texas, Md.	70.00 (40M)	61.80 (40M)	52.20 (40M)	60.00 (40M)	—
	52.20 (60M)	45.80 (60M)	33.80 (60M)		
	1109 km	843 km	584 km	747 km	—
North Adams, Mass.	73.20 (40M)		56.20 (40M)	62.00 (40M)	
	52.20 (60M)		43.20 (60M)		—
	1370 km	1104 km	829 km	689 km	
Kaolin					
McIntyre, Ga.	41.19 (60M)	42.82 (60)	42.82 (60M)	54.05 (60)	44.00 (60M)
	33.85 (90M)	35.20 (90M)	35.20 (90M)	44.31 (90M)	36.16 (90M)
	1270 km	1300 km	1247 km	1632 km	1394 km
Langley, S.C.	41.19 (60M)	—	—	54.05 (60M)	44.00 (60M)
				44.31 (90M)	35.97 (90M)
	1238 km		1051 km	1468 km	1210 km
Mica					
Spruce Pine, N.C.	27.83 (80M)	32.20 (100M)	31.20 (100M)	86.24 (100M)	34.80 (100M)
	995 km	912 km	816 km	1228 km	1060 km
Silica					
Mapleton, Penn.	41.80 (65M)	36.00 (65M)	29.60 (65M)	49.80 (40M)	—
	938 km	673	409 km	546 km	415 km
Elco/Tamms, Ill.	31.60 (80M)	27.62 (80M)	27.71 (80M)	43.20 (40M)	—
	30.60 (80M)				
	562 km	879 km	914 km	1250 km	1577 km
Talc					
Johnson, Vt.	57.20 (60M)	51.40 (60M)	46.80 (60M)	50.80 (80M)	39.20 (60M)
	53.00 (100M)	47.00 (80M)	43.60 (80M)		35.40 (80M)
	1506 km	1241 km	966 km	713 km	534 km
Gouverneur, N.Y.	57.00 (60M)	47.40 (60M)	49.00 (60M)	41.60 (60M)	41.80 (60M)
	1226 km	961 km	686 km	412 km	562 km
Barretts, Mont.	54.00 (120M)	—	67.40 (120M)	89.40 (90M)	78.00 (120M)
	2408 km	2836 km	2948 km	3207 km	3690 km

* M = 1,000 pounds

tion equipment which often is custom designed to the needs of both the producer and consumer.

As a product group, fillers are far different from the bulk of industrial minerals in regard to transportation and distribution complexity. For most industrial minerals, point-to-point freight rate comparisons can develop freight favorable zones and areas of primary market influence not generally possible for fillers.

Freight rate comparisons shown in Table 71 list representative shipping points and typical destinations in the study area for the six mineral fillers being reviewed. The rates were developed from the originating carrier's rate office in March, 1981, and as they do not include applicable surcharges, if any, are only approximate. The following example will help interpret the data in Table 71.

Mineral
-Barite

Origin
-Cartersville, Georgia

Destination
-Chicago, Illinois

Freight Rate
-$US 42.00 per short ton

Minimum Weight Shipped
-80,000 pounds

Highway Mileage
-1086 km

In examining the freight rate structure (Table 71) it will be seen that the higher the minimum weight of the filler shipment, the lower the cost per ton. Kaolin rates to the state of Maine were about $36 per ton for minimum bulk hopper car shipments of 100 tons in 1981, substantially lower than the rates to New York City for smaller loads and a shorter haul.

In some instances combination loads are possible in meeting minimum load requirements, such that both barite and calcium carbonate can be shipped together from Cartersville, Georgia, for example.

It will also be noted that point-to-point rail costs are not necessarily proportional to the distance hauled, and this can also vary with different commodities shipped. When an international boundary is crossed, the rail rate increases substantially. For example, the rate for calcium carbonate from Cartersville, Georgia, to Buffalo, New York, is $42.50 per ton for a minimum load of 80,000 pounds, but is $81.20 to Toronto for the same minimum load.

An estimate of long haul truck rates is even more difficult than for rail. Traditionally, hauls of more than 200 km have favoured rail while trucks handled the shorter hauls. But with rail rates escalating faster than trucking rates in many instances, and because of the greater convenience of trucking and lower inventory requirements, longer distance truck hauls are increasingly attractive. Increasingly, trucks are being favoured over distances up to 500km; markets that can be serviced within a 24-hour round trip time frame.

Rates for these longer hauls are inevitably negotiated and constantly reviewed; or a producer may operate his own fleet of highway vehicles. The successful independent hauler will often be the one who enjoys some advantage, such as load movements in both directions. Trucking rates of 5 to 10 cents per tonne kilometre can be expected to the mid 1980's for longer highway hauls.

Nevertheless, changes in rail policy, such as the recent deregulation of much railroad activity in United States, may again tip the scale in favour of rail haulage in the future, as it has done in the past. Just as it is not possible to readily estimate haulage rates between two given points, so is it not possible to forecast the most favoured mode of transport in the years ahead.

Optimum haulage rates can only be determined by comparative analysis with a variety of carriers for specific minerals from specific sources to specific destinations for specified minimum loads.

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